BBSQ

Environment Canada | Environnement Canada

Canada - Ontario Agreement on Great Lakes Water Quality

Ministry of the Environment
Ontario

Full-Scale Evaluation of High Rate Screening Devices for Treatment of Sanitary Sewage By-Pass Flow

Research Report No. 103

Research Program for the Abatement of Municipal Pollution under Provisions of the Canada-Ontario Agreement on Great Lakes Water Quality

CANADA-ONTARIO AGREEMENT

RESEARCH REPORTS

These RESEARCH REPORTS describe the results of investigations funded under the Research Program for the Abatement of Municipal Pollution within the provisions of the Canada-Ontario Agreement on Great Lakes Water Quality. They provide a central source of information on the studies being carried out in this program through in-house projects by both Environment Canada and the Ontario Ministry of Environment, and contracts with municipalities, research institutions and industrial organizations.

Inquiries pertaining to the Canada-Ontario Agreement RESEARCH PROGRAM should be directed to -

Wastewater Technology Centre
Canada Centre for Inland Waters
Environment Canada
P.O. Box 5050
Burlington, Ontario L7R 4A6

Ontario Ministry of Environment
Pollution Control Branch
135 St. Clair Avenue West
Toronto, Ontario M4V 1P5

BBSQ

FULL-SCALE EVALUATION OF HIGH RATE SCREENING DEVICES FOR TREATMENT OF SANITARY SEWAGE BY-PASS FLOW

by

H. Kronis and F. Tonelli
Pollution Control Branch
Ministry of the Environment

RESEARCH PROGRAM FOR THE ABATEMENT OF
OF MUNICIPAL POLLUTION WITHIN THE
PROVISIONS OF THE CANADA-ONTARIO
AGREEMENT ON GREAT LAKES WATER QUALITY

Project No. 72-1-22

This document may be obtained from -

Training and Technology Transfer
Division (Water)
Environmental Protection Service
Environment Canada
Ottawa, Ontario
K1A 1C8

Ontario Ministry of the Environment
Pollution Control Branch
135 St. Clair Avenue West
Toronto, Ontario
M4V 1P5

Cat. No. En 43-11/103E
ISBN 0-662-11182-6
BEAUREGARD PRESS LIMITED

ABSTRACT

The performances of four fine-mesh high-rate screening devices treating combined sewage under wet and dry weather conditions were evaluated. The units tested were: a 1.5-m (60-inch) diameter Centrifugal Wastewater Concentrator (CWC) with 105-micrometre apertures; a 1.5-m (60-inch) long rotating horizontal drum screen (Rotostrainer) with 500-micrometre apertures; and two stationary inclined screens, a 0.6-m (24-inch) wide DSM and a 1.8-m (72-inch) wide Hydrasieve, having 305 and 762-micrometre apertures, respectively. The study was conducted during 1974/75 at the Belleville, Ontario, Water Pollution Control Plant, where influent sewage is subject to substantial infiltration, dilution, and flow peaking during wet weather.

Hydraulic capacity and pollutant removal depended largely on the type of screening device, the screen aperture size, and the availability of an effective backwash system. Hydraulic capacities were between 0.78 to 2.4 $m^3/m^2 \cdot min$ (16 and 50 $gal/min \cdot ft^2$). Typical mean pollutant removals obtained during storm events with first flush conditions were between 5 and 32 percent for suspended solids, 5 and 24 percent for BOD_5, and 23 and 79 percent for settleable solids. In general, pollutant reductions were substantially less in dry weather.

Operating costs were estimated to be between 0.13 and 4.2 cents per cubic metre (0.6 and 19 cents per 1000 gallons) treated depending on, among other factors, installed capacity, the number of hours of operation, and the device evaluated.

It was concluded that screening had potential for the reduction of pollutants in combined sewer flows.

RÉSUMÉ

On a évalué l'efficacité de quatre tamis fins à débit élevé pour traiter des effluents unitaires, par temps humide de sec, à l'usine d'épuration de Belleville (Ontario) en 1974-1975. Il s'agissait d'une centrifugeuse Centrifugal Wastewater Concentrator (CWC) de 1,5 m (60 po) de diamètre at à ouvertures de 105 μ; d'un tambour Rotostrainer horizontal rotatif de 1,5 m de longueur à ouvertures de 500 μ; et de deux tamis inclinés DSM et Hydrasieve de 0,6 m (24 po) et 1,8 m (72 po) et à ouvertures de 305 et de 762 μ, respectivement. Par temps humide, les eaux à traiter subissent des infiltrations et des dilutions notables et leur débit est maximal.

La vitesse de tamisage et le taux d'épuration dépendaient en grande partie du type de tamis, de la grandeur des ouvertures et de l'efficacité du lavage en retour. Ainsi, la vitesse variait entre 0,78 et 2,4 $m^3/m^2 \cdot min$ (16 et 50 $gallons/min \cdot pi^2$); le taux d'épuration des premières eaux de période d'orage, entre 5 et 32% de MES, 5 et 24% de la DBO_5 et 23 et 79% de matières décantables. Par temps sec, le taux d'épuration était dans l'ensemble beaucoup moindre.

On a évalué les coûts d'exploitation entre 0,13 et 4,2 ¢/m^3 traité (0,6 et 19¢ pour 1000 gallons), selon, entre autres facteurs, la grosseur du tamis, le nombre d'heures de fonctionnement et le type du tamis.

En conclusion, le tamisage peut servir à l'épuration des eaux d'égouts unitaires.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The Centrifugal Wastewater Concentrator (CWC) and the stationary hydraulic or DSM screen produced good removals of settleable solids and moderate removals of suspended solids, BOD_5, and nutrients. Removals of settleable solids exceeded 90 percent in some cases. Removals of other parameters were significantly lower and rarely exceeded 20 percent. The Hydrasieve, without a cleaning device, and the Rotostrainer produced considerably lower removals and can be considered as roughing devices only.

The largest pollutant removals were attained under first flush storm conditions. Although increased pollutant levels in the raw sewage enhanced removals, pollutant concentrations were also increased in the screened effluents. Removals were lower during storms without a first flush and when dry-weather sanitary sewage was treated. Screen performance on dry-weather sewage was always below primary clarifier efficiency.

The DSM screen, Rotostrainer, and Hydrasieve produced sludges with solids contents between three and eight percent. The CWC produced a centrate that had between 10 and 40 percent of the influent volume and required further treatment. The major portion of mass solids removal with the CWC was due to hydraulic flow splitting rather than to increased solids concentration in the concentrate. No additional removals were achieved by the flotation cell associated with the CWC. The CWC concentrate settled as well as or better than raw sewage and was effectively concentrated to a sludge by the DSM screen.

Acceptable flow rates to the units were between 0.78 and 2.4 $m^3/m^2 \cdot min$ (16 and 50 $gal/min \cdot ft^2$). The DSM screen had the lowest flow rate while the CWC had the highest. The hydraulic capacities of the CWC and DSM screen were limited by the effectiveness of the screen backwash systems. Slugs of industrial oil and grease in the influent were responsible for continuing problems due to screen blinding.

In-line screen cleaning for the CWC required a source of hot water with a suitable chemical degreaser. Continuous cold water backwash

and occasional manual cleaning were also required. Prior to modification of the backwash system, the unit failed completely during the first flush of severe storm events. The DSM screen performed well with a reciprocating mechanical brush but not with a spray cleaning system. Occasional manual cleaning was also required. The performance of the Hydrasieve could be significantly improved with a continuously operating cleaning device. Only the Rotostrainer with the 500-micrometre aperture screen cylinder was truly self-cleaning. An insufficient number of storm events precluded evaluation of the full potential of this unit. With the required modifications, all four devices could be automated.

The life of the CWC screen panels was about 500 operating hours. Certain types of screen failure could be repaired. The media of the DSM screen, Hydrasieve, and Rotostrainer showed no visible wear during the test period.

Estimated capital costs for 1976 were between $\$3.72/m^3 \cdot d$, ($16 900/mgd), for the Rotostrainer, and $\$4.80/m^3 \cdot d$ ($21 850/mgd) for the DSM screen. At an operating time of 100 hours per year, operating costs were between $2¢/m^3$ (9¢/1000 gal) for the Rotostrainer, and $4.2¢/m^3$ (19¢/1000 gal) for the CWC. Corresponding figures for 8000 hours per year were 0.13 and $1.1¢/m^3$ (0.6 and 5¢/1000 gal). Costing estimates were not made for the Hydrasieve because it did not have a screen cleaning device.

Recommendations

On the basis of the results in this study the following recommendations are made:

a) The performance of the screens in treating dry and wet-weather combined sewage should be evaluated at a water pollution control plant that has higher influent levels of suspended solids than were obtained at Belleville.

b) In further evaluations of the CWC, prescreening should be provided using either the Rotostrainer, DSM Screen or Hydrasieve, to reduce puncture type failures.

c) The durability of the CWC screen media should be improved.

d) The CWC backwash system should be improved. An important requirement is the identification of a chemical degreaser that is compatible with screen gaskets.

e) A screen cleaning device should be developed for the Hydrasieve.

f) The use of hydraulic sprays for cleaning the underside of the DSM screen panel should be considered.

g) Methods for further treatment or thickening of the CWC concentrate should be investigated.

1 INTRODUCTION

Combined sewer overflows make a significant contribution to the pollution problems of many receiving waters adjacent to urban areas in Canada and the United States [1]. In Ontario, water quality problems in the near-shore areas of the Great Lakes have been attributed to this source [2].

Combined sewer overflows typically result from peak sewage flow rates caused by rapid runoff of surface water into the sewerage system during significant precipitation. Whether or not overflow occurs depends on many factors, including the collector system and water pollution control plant (WPCP) design and the intensity and duration of the precipitation. Overflows can occur either within the sewerage system or at the WPCP.

Two traditional approaches to the handling of peak flows at the WPCP are the provision of "storm tanks" for short-term storage and subsequent return to the treatment system, and sizing the primary clarifiers to handle flow rates in excess of secondary treatment capacity. These approaches can be effective in lowering the quantities of pollutants discharged to receiving waters in situations where peaking factors are moderate and most of the sewage flow is routed to the WPCP. Only within the last few years has treatment technology for abatement of pollution from combined sewer overflows become available.

Both primary and secondary treatment have been demonstrated in projects of the U.S. Environmental Protection Agency (EPA) [1]. Screening has been regarded as a potential primary treatment to be followed either by disinfection and discharge or by secondary treatment such as biological and physical-chemical processes. Little operating or performance data relating to screening technology have been gathered in Canada to the present time. The Urban Drainage Subcommittee of the Canada-Ontario Agreement, while developing a strategy for abatement of combined sewer overflows, decided to sponsor a field study to evaluate some of the available screen types. The Wastewater Treatment Section of the Ontario Ministry of the Environment carried out the study at the Belleville WPCP during 1974 and 1975.

The primary objectives of the program were:

1. to investigate the performance of several full size high-rate screening devices in the treatment of wet weather raw sewage flows at a single WPCP, and
2. to determine the efficiency and cost of such treatment with the different types of screens.

A secondary objective was to investigate the use of the different screens in dry weather conditions as primary and, in the case of the Centrifugal Wastewater Concentrator, tertiary treatment devices, and thus to determine their potential for multiple use in both dry and wet weather.

2 SCOPE OF THE PROGRAM

Full-size screening units were used in order to avoid having to scale up the results. Initially, only the Centrifugal Wastewater Concentrator (CWC) and Hydrasieve were to be studied, but two other screens were added after the program was underway as they would provide additional test data with little additional effort or expense. It was recognized that the units varied in their potentials for pollutant reduction and for multiple

Duration of the study was fixed at two operating seasons in order to provide sufficient time for a meaningful assessment of screen performance under storm conditions. To assess the possibility of multiple use, dry weather operation was undertaken. Operation in dry weather was also essential to accumulate enough operating hours to estimate the screen life for the CWC. No winter operation was attempted because of the excessive costs of constructing and maintaining winterized facilities.

Two major types of test parameters were evaluated: "design" parameters needed for rating or sizing the equipment; and "performance" parameters that indicated pollutant reduction and the expected degree of solids concentration achieved by the process. The major design criteria were: screen type, screen mesh or aperture, hydraulic loading, required total dynamic head of the feed pump, and suitability for automated operation. The respective equipment suppliers claimed that screen mesh or aperture, hydraulic capacity, and screen cleaning systems had been optimized; initial emphasis was therefore placed on the other factors. The general reliability of the major and auxiliary equipment was also evaluated.

Pollutant removal efficiency was assessed in terms of the reductions in settleable matter and suspended and volatile suspended solids, and the associated removal of BOD_5, COD, and nutrients. Occasional checks were made on reductions in ether-extractables and bacteria. Hydraulic capacity was assessed in terms of nominal (instantaneous applied) loading of sewage per unit area of screen surface ($m^3/m^2 \cdot min$ or $gal/min \cdot ft^2$). Corrected estimates of loadings, which allowed for factors such as screen cleaning time, were also made. In addition, the usage rate and effectiveness of various cleaning methods and/or cleaning agents for the screens were assessed.

Capital and operating cost estimates were based on actual performance data generated at Belleville.

3 TECHNICAL BACKGROUND

3.1 General Discussion

Screening is a physical process for separating solids from liquids in which the liquid phase passes through a regularly-spaced woven or perforated fabric or media. Depending on the particular screening process employed, the size of the screen opening (aperture) and the particle size distribution of the solids, some fraction of the solids is retained by the media and can then be removed either as a sludge or as a solids-enriched concentrate. Typically, sludges have solids concentrations in the range of three to 15 percent. Concentrates can have solids levels as low as twice those in the liquid feed to the screen. Further enrichment of concentrates can be obtained by multi-stage screening.

Since the overall efficiency of screening at best approaches that of simple sedimentation, it is usually followed by other processes. Suspended solids reduction can be improved with some types of screens by increasing the effective particle size in the wastewater through chemical coagulation. When chemical coagulation is employed pollutant removals can exceed those obtainable by sedimentation.

Although the percentage reduction of suspended matter is increased by the use of screens with smaller openings, the hydraulic capacity of fine screens is reduced because of the reduction in effective open area per unit of nominal screening surface. Progressive blinding or blockage of the media also reduces hydraulic capacity by decreasing the effective size of the apertures. Much effort has been expended by manufacturers to develop screen designs and cleaning systems which minimize blinding. Depending on the cleaning system employed, screens have batch or continuous operation. For batch screening, cleaning systems have been developed to minimize downtime when blinding does occur.

3.2 Classification and Potential Application of Screening Devices

Screening equipment used for wastewater treatment can be classified into four groups: bar screens, coarse screens, fine screens, and micro-screens.

Bar screens, which have openings of the order 25 to 75 mm (one to three inches), have been used extensively in sewage treatment. These

screens serve only as roughing devices to remove gross particulate matter and protect equipment used in subsequent treatment.

Coarse screens, with openings in the range 5 to 25 mm (3/16 to 1.0 inch), also give limited pollutant removal. Typically, these screens are used as protective devices ahead of other equipment or processes, and to improve the appearance of the wastewater before disinfection or immediate discharge.

Fine screens and micro-screens can remove significant quantities of suspended matter, which may also include BOD_5 and nutrients. Fine screens have openings of the order 33 to 104 micrometres (450 to 165 mesh); openings of micro-screens are generally in the range 23 to 65 micrometres (600 to 225 mesh). Fine screens appear to have considerable potential for application to the treatment of combined sewer overflow (CSO) and other sanitary wastes. Numerous mechanical and blinding problems have been noted in evaluations of micro-screens used in CSO applications [1]. Principal screen characteristics of the three types of fine-mesh screening devices evaluated in this study are summarized in Table 1. The pollutant removal values are approximate as they are based mainly on performance for short periods of wet weather operation with pilot-scale units.

3.3 Operating Principles

3.3.1 Centrifugal wastewater concentrator (CWC)

The CWC was developed by SWECO Inc. to provide primary treatment by concentrating suspended solids in sewage. Seventy to 90 percent of the influent volume is discharged as clarified screen effluent (centrate) while the remaining volume or concentrate requires further treatment.

The centrifugal wastewater concentrator incorporates features of both a microstrainer and a centrifuge. A diagram of a section of a typical concentrator is shown in Figure 1. The entire screen assembly is contained within a stationary outer casing with appropriate inlet and outlets. Influent is pumped into the unit through a stationary central distributor and directed at a rotating screen cage. Most of the liquid passes through the rotating screen cage while the bulk of the solids is retained and then discharged from the bottom. Backwash sprays from both

TABLE 1. CHARACTERISTICS OF SCREENS USED FOR TREATMENT OF COMBINED SEWER OVERFLOW [1]

	Rotary Screen	Drum Screen	Hydraulic Sieve
Potential Use	Pretreatment Primary Treatment Effluent Polishing	Pretreatment	Pretreatment Primary Treatment
Screening Surface	SS-TBC*	SS-Wedge Wire	SS-Wedge Wire
Aperture Size (micrometres)	105-325	250-1500	250-1500
Hydraulic Capacity	2.0-5.0 $m^3/m^2 \cdot min$ (40-100 gpm/ft^2)	0.8-5.5 $m^3/m^2 \cdot min$ (16-112 gpm/ft^2)	0.7-2.8 $m^3/min \cdot m$ (4-16 gpm/inch)
Operating Mode	Batch	Continuous	Continuous/Batch
Pollutan Removal (%)			
Settleable Solids	60-90	--	--
Suspended Solids	<35	40	5-25
BOD_5	<15	15	--
Concentrate/Sludge (% of total flow)	10-20	0.5-1.0	0.5
Screen Life	1000 hours	10 years	20 years
Screen Cleaning	Yes	Optional	Optional when available
Automatic Operation	Possible	Possible	Possible

*SS-TBC = Stainless Steel - Tensile Bolting Cloth.

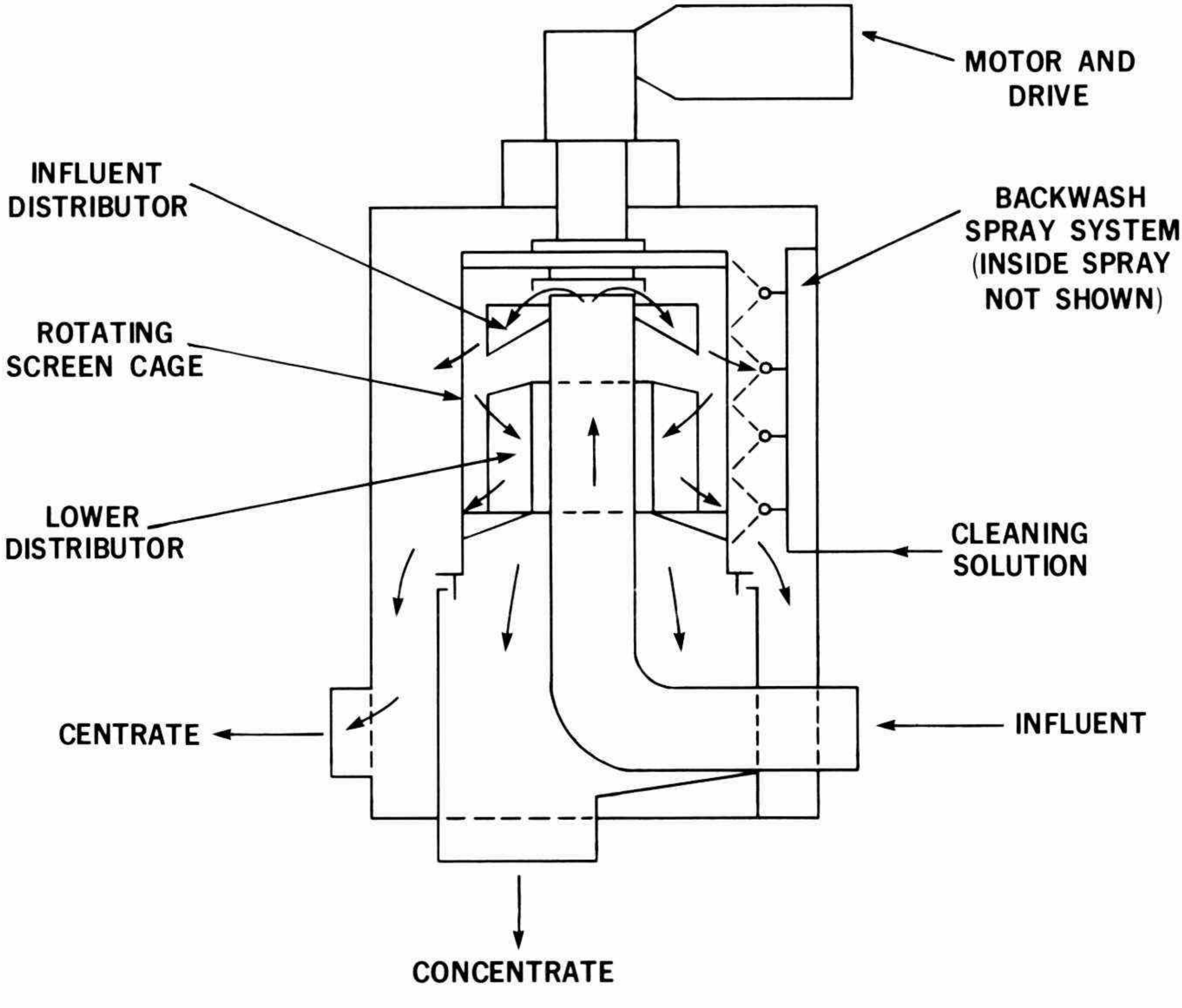


FIGURE 1. SCHEMATIC OF CENTRIFUGAL WASTEWATER CONCENTRATOR

outside and inside the cage prevent blinding. The device operates on a cyclic basis; after a preset screening period the process is interrupted by a cleaning cycle. Overall performance of the CWC is a function of the mesh size of the screen, the rotational speed of the screen cage, the velocity at which the liquid hits the screen, the strength and durability of the screen material, and the efficiency of the backwash operation.

During the development of the concentrator it was found that a rotating screen provided greater removal of settleable solids than could be accomplished by stationary or vibrating screens [3]. Furthermore, the efficiency of removal of settleable solids was increased as the rotational speed was increased to an optimum value. As the rotational speed increases, it becomes progressively harder for a particle approximating the size of the openings to pass through. As a result, particles smaller than the opening are rejected by the revolving screen and form a film over the screen, subsequently to be carried off in the concentrate. This film also protects the screen from sharp objects. At 60 rpm a 1.5-m (60-inch) diameter screen cage develops about 3 g's of centrifugal force, a value which appears to be the optimum for achieving a satisfactory hydraulic split. The centrifugal force, while important for achieving separation of the water from the solids, must not be so great that solids cling to the screen and cause blinding. At the optimum rotational speed the concentrate will flow down the screen from the force of gravity [4]. An optimum velocity of 1.5 to 4.5 m/s (5 to 15 ft/s) has been established for the incoming feed.

Screens with 105, 165, and 230-mesh apertures were previously evaluated by the manufacturer [3]. The 105-mesh screen had excellent hydraulic performance but low solids removal, whereas the 230-mesh screen had excellent removal efficiencies but were so fine that hydraulic stresses caused them to fail repeatedly. The 165-mesh screen had good hydraulic capacity and adequate solids removal efficiency. Current indications are that it may be possible to build stronger screens with a 230-mesh opening. A typical screen panel, one of 36 used in a 1.5-m (60-inch) diameter CWC, is shown in Figure 2. The screening material, stainless steel tensile bolting cloth (SS-TBC), is attached with epoxy cement to a fibreglass frame.

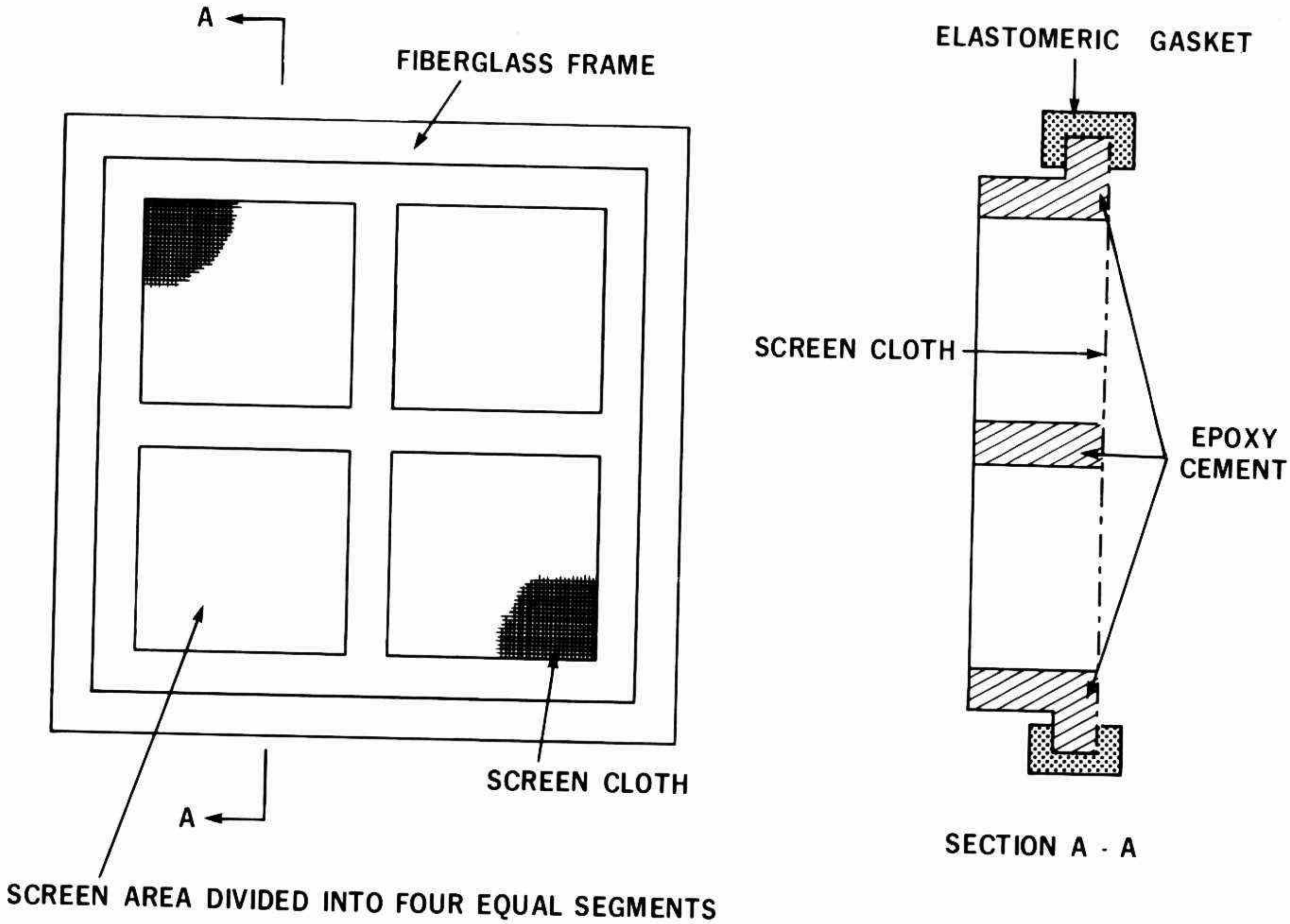


FIGURE 2. CWC SCREEN PANEL WITH GASKET

The CWC can be used in conjunction with a flotation cell. The manufacturer has suggested that air which was entrained during the screening process could float some of the solids in the centrate. The resulting scum or foam would be collected from the surface of the tank by a rotating paddle, or similar device, discharging to a scum trough.

With the CWC, pollutant removal from the influent occurs by "enrichment" (decreases in concentration) and by hydraulic flow splitting. Evaluation of pollutant removal can be based on either concentration changes (enrichment) across the screen medium (a method generally used when a negligible volume of disposable sludge is produced) or on both enrichment and hydraulic flow splitting. If CWC performance is to be compared with the performances of devices that produce a small volume of disposable sludge, then mass transfer by enrichment only should be considered. This value is obtained from the concentration change across the screen media (influent-centrate) and the centrate hydraulic fraction. Mass transfer by hydraulic flow splitting alone is always identical to the fraction of the influent flow which becomes concentrate and is usually in the range 10 to 30 percent. For optimum screen performance mass transfer by enrichment should be at a maximum and the concentrate fraction should be at a minimum.

3.3.2 Stationary hydraulic sieve (DSM)

Originally, the DSM screen was designed for solids or aggregate separation in the mining industry by Dutch State Mines. More recently it was applied to industrial waste treatment, especially in the food processing industry, and it has now been introduced in the municipal sector.

The basic design of the DSM screen is illustrated in Figure 3. The unit consists of a housing equipped with a stationary, concave, wedge-wire screen. Provision is made for introducing feed tangentially to the wedge-bar surface and withdrawing effluent containing undersize particles. Oversize particles roll down the screen and can be collected or conveyed for further processing.

The principle of operation is illustrated in Figure 4 [5]. The influent (raw sewage) is directed vertically and tangentially over the full

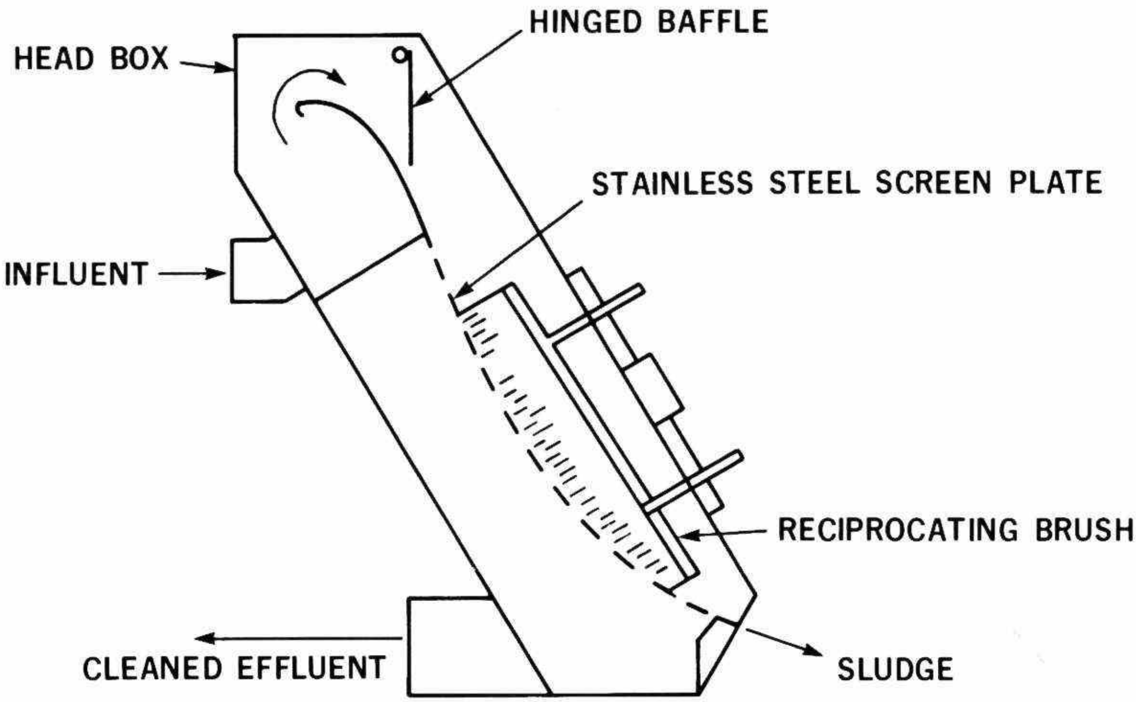


FIGURE 3. SCHEMATIC OF 24-INCH WIDE 45° DSM SCREEN

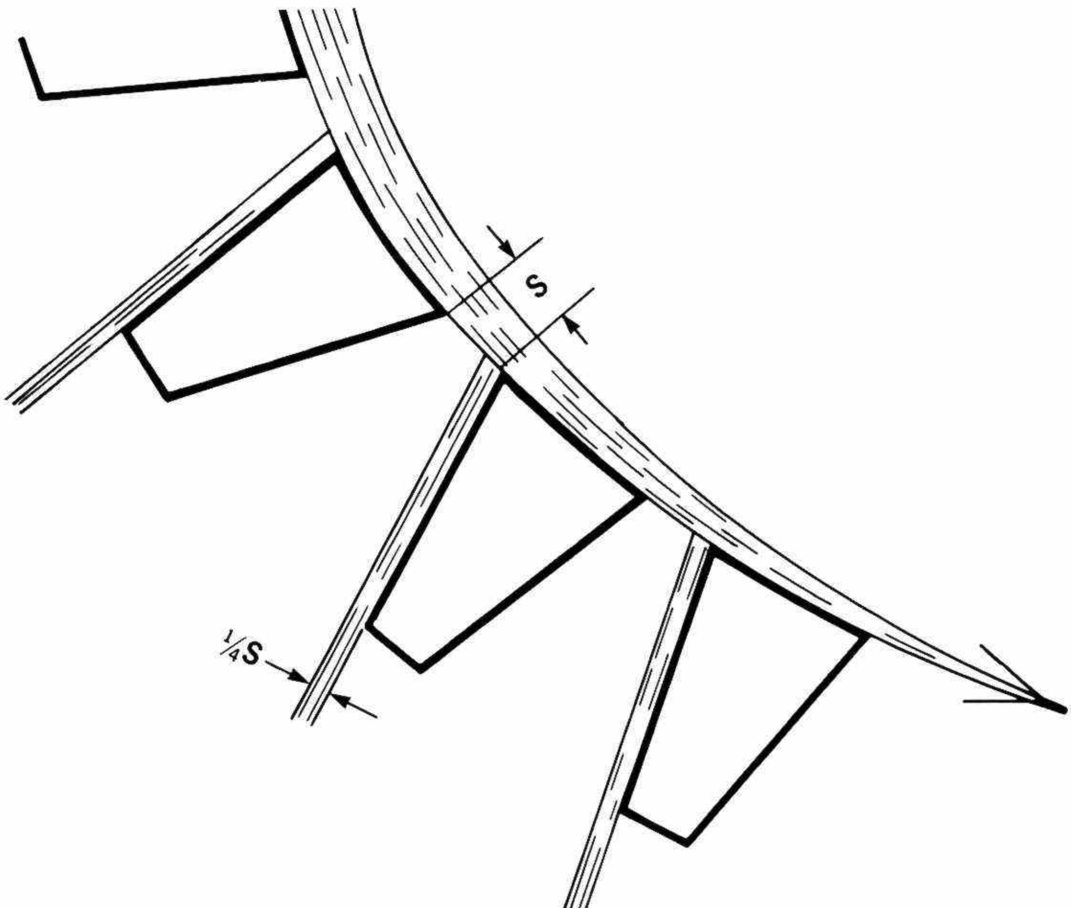


FIGURE 4. PRINCIPLE OF DSM SCREEN OPERATION

width of the upper screen surface. The slurry flows down the concave surface at right angles to the openings between lateral wedge bars, and a thin layer at the screen surface is deflected and passes between the bars. Apparently the size of separation for particles is determined by the thickness of this layer rather than by the width of the openings between the bars. The layer passing through the slots is typically about one-quarter the slot thickness. It is claimed for screens with slots of 100 micrometres or larger, which are applicable to waste treatment, that the layer passing through the screen will normally entrain particles with a diameter smaller than one-half the slot thickness. Previous experimental work by the supplier showed that fine DSM screens with slot openings of 100 micrometres (0.004 inches) or less produced a separation of solids close in size to that of the slot opening. Screening action is claimed to be further enhanced by the increase in particle size or agglomeration that takes place as the material moves down the inclined screen media.

The influence on screen performance of variables such as the opening between wedge-wire bars, velocity across the screen surface, radius and length of screen, feed layer thickness, screen width and profile of wedge-wire bars has been discussed elsewhere [5].

Currently, the manufacturer has developed two methods of screen cleaning for application in the food processing industry: hydraulic backwash sprays and a reciprocating mechanical brush. Operation is continuous with the mechanical brush and intermittent with the hydraulic sprays.

3.3.3 Stationary inclined screen (Hydrasieve, Bauer Inc.)

This device is shown schematically in Figure 5. Apart from variations due to screen design its operating principles are similar to those of the DSM screen. The Hydrasieve was initially designed for industrial waste treatment but has been used in municipal wastewater treatment.

The screen plate is a one-piece assembly of specially-shaped transverse bars (wedge-wire) having three distinct slopes. Each slope is claimed to have a specific function [6]: most of the free fluid is stripped on the first or 25° slope; additional fluid is removed on the

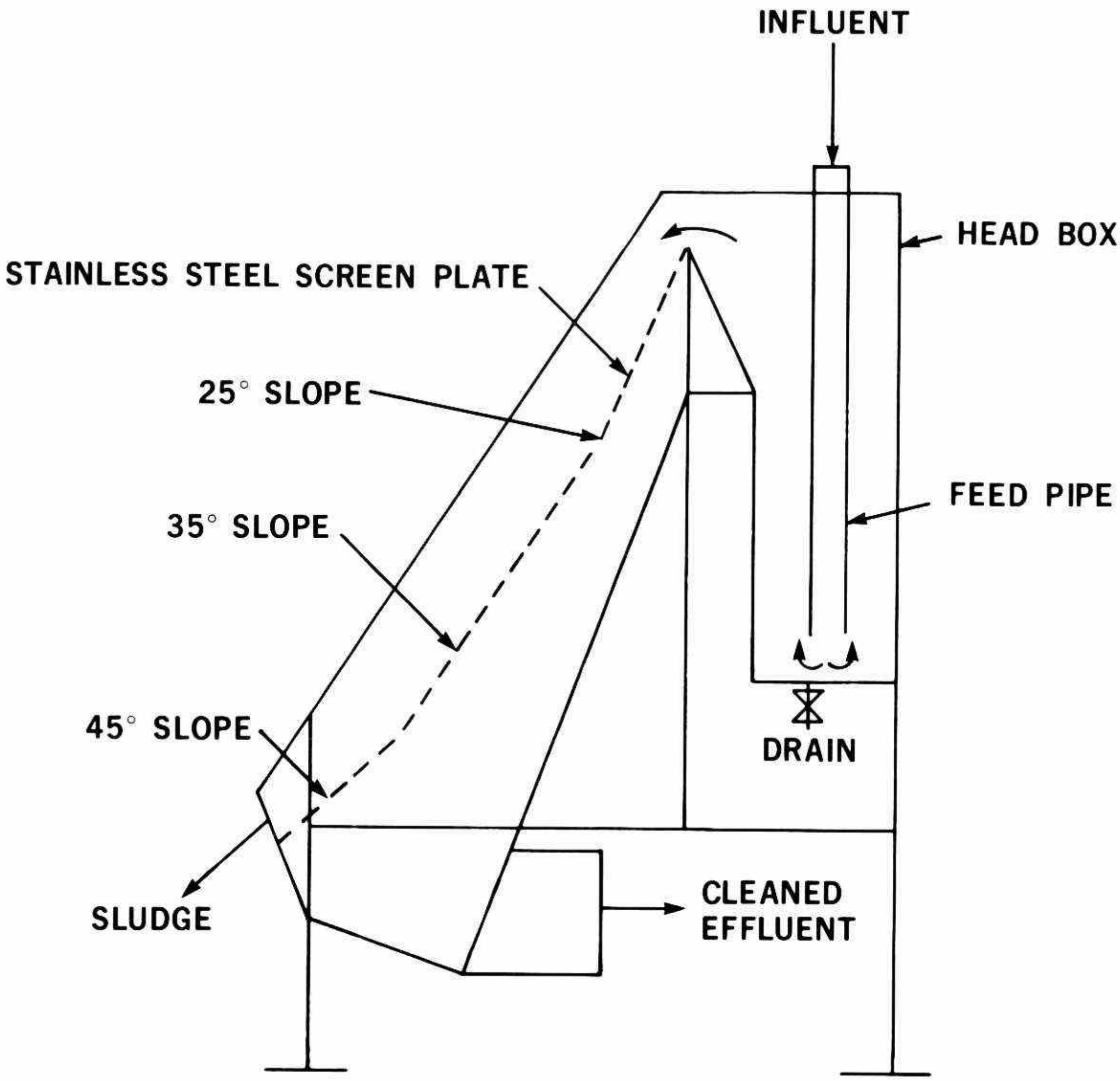


FIGURE 5. SCHEMATIC OF HYDRASIEVE

second or 35° slope, while solids roll downward; on the final, 45°, slope solids are decelerated for drainage. The specially wound wedge-wires that curve downward between the vertical supports are claimed to centre the flow between the supports and hence reduce screen clogging or blinding. A further factor claimed to reduce screen blinding is the wedge-bar shape of the screen wire, which promotes the stripping of liquid from the bottom of the screen. Screen variables affecting performance are similar to those described for the DSM unit.

The manufacturer claims that the Hydrasieve is self-cleaning, and consequently no screen cleaning device is available.

3.3.4 Rotostrainer (Hydrocyclonics Inc.)

The Rotostrainer was developed mainly for use as a roughing or pretreatment device within wastewater treatment systems. Its operation and performance are significantly different from those of the screening devices discussed previously. Operationally, it bears some resemblance to a microstrainer. The basic design of the Rotostrainer is shown in Figure 6. Influent enters the headbox assembly and flows continuously through the slowly rotating cylindrical drum screen [7]. The solids that cannot pass through the screen openings ride over the top of the screen and are removed by the wiper blade and directed away from the screen to a suitable collection system. The effluent passes through the top of the screen, falls through the interior, and leaves at the bottom. The large volume of falling filtrate backwashes any particles trapped between the screen openings that were not removed by the wiper blade. The Rotostrainer is thus claimed to be self-cleaning in most applications. A supplementary backwash spray system is available, however.

The Rotostrainer operates with a head of liquid against the drum rather than a thin film of fluid moving across the screen, but only about one-quarter of the available screen surface is in contact with the applied liquid at any time. Screen construction differs from that of inclined screens in that wedge-wire is wrapped around a supporting structure to form a helical coil. Drum speed is variable to assist in maintaining hydraulic capacity at different loadings of suspended matter.

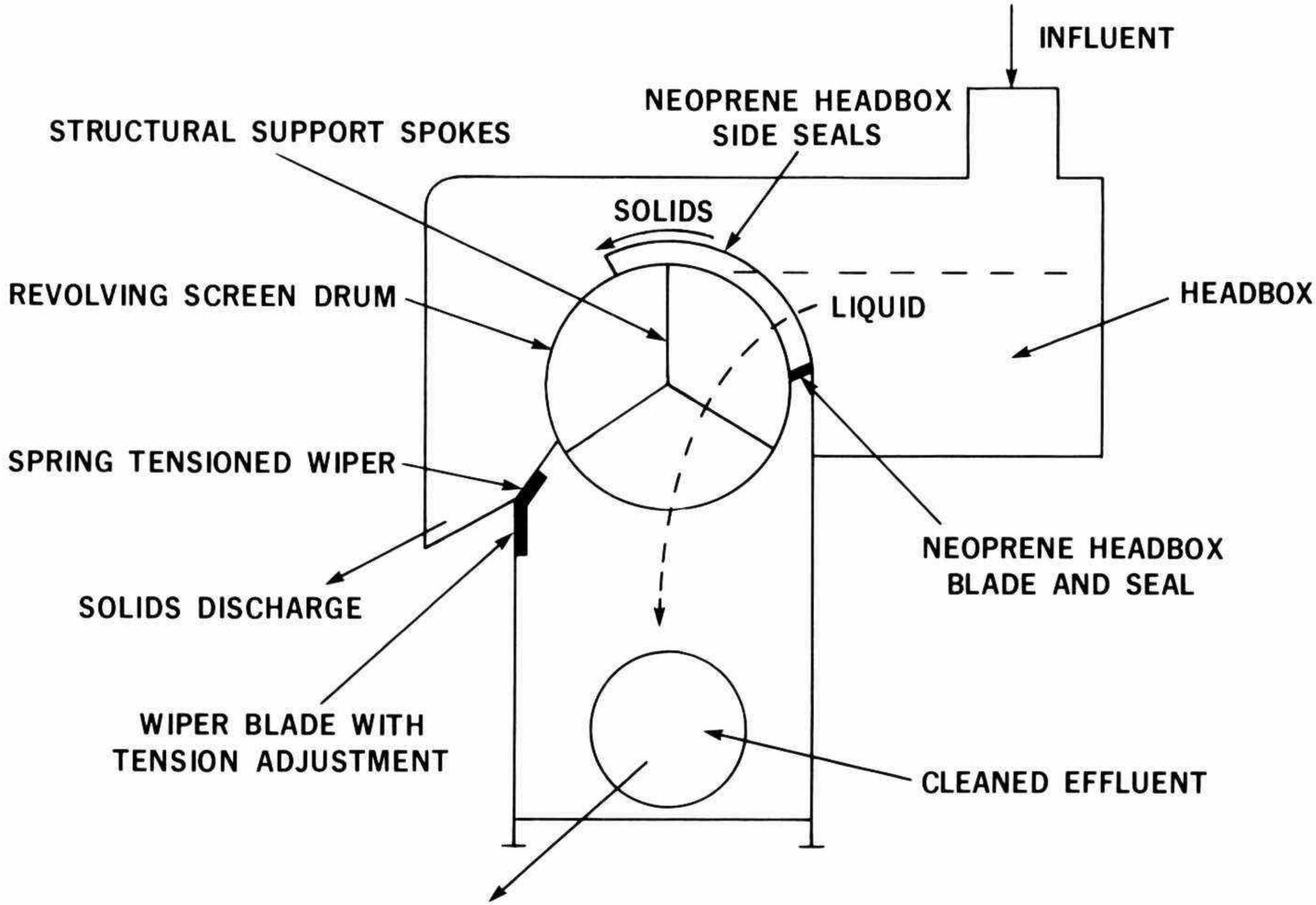


FIGURE 6. SCHEMATIC OF ROTOSTRAINER

4 DESCRIPTION OF STUDY AREA

4.1 Site Selection

Belleville was chosen over a number of other sites for both experimental and operational reasons. It has a history of significant sewage dilution following rainfall, a peaking factor likely to result in some by-pass activity, and above-normal per person water consumption and sewage flows. Ease of installation for both raw sewage screening and final effluent polishing and the availability of sufficient electrical capacity also were factors in the selection of Belleville for this study.

4.2 City of Belleville

The City of Belleville is located on the northern shoreline of the Bay of Quinte on Lake Ontario. The city has an area of 2350 ha (5800 acres) and a population of 36 000. The area is underlain basically with limestone, and the terrain rises gently from the Bay. The Moira River flows in a southerly direction through the centre of Belleville and discharges into the Bay. The climate is moderate for Ontario, with temperatures ranging from a monthly mean minimum of -18°C (0°F) in winter to a monthly mean maximum of 29°C (85°F) in summer. Average monthly precipitation is in the range of 18 to 90 mm (0.7 to 3.5 inches), higher values generally occurring between March and November.

4.3 Sewerage System

The sewer system is mainly separated with surface runoff draining to storm sewers. A 50-ha (125-acre) section of the older downtown is serviced by combined sewers and occasional basement flooding occurs in this area. Roof runoff from a large but unknown proportion of buildings enters the sanitary sewers.

By 1974 virtually all developed land in the City of Belleville was served by sewers. The sewerage system is divided into two major areas each with a major pumping station: the "Front Street" and "Plant" pumping stations. The area served by the Front Street pumping station, which includes the combined sewer area, is shown in Figure 7. This area comprises 65 percent of the developed land and 65 percent of the total population of Belleville. The capacity of the Front Street pumping station is 0.74 m^3/s (14.25 mgd). Provision has been made at the

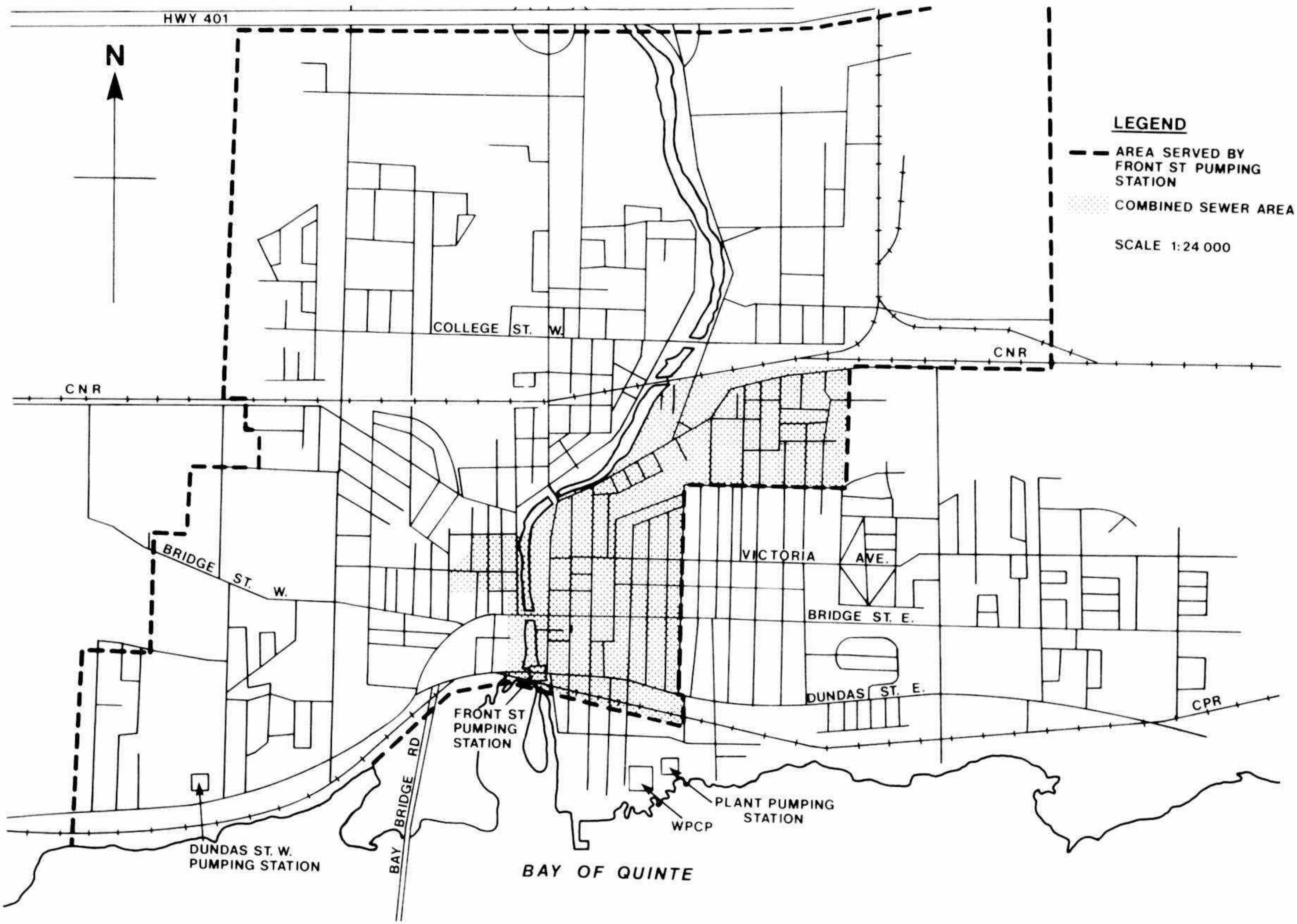


FIGURE 7. CITY OF BELLEVILLE SEWERAGE AREAS

pumping station for manual or automatic by-passing during peak flows. The Plant pumping station has a capacity of 0.42 m^3/s (8.0 mgd) and serves the eastern part of the town. Although provision for by-passing exists at this station, records indicate that flows from this area have never exceeded pumping capacity and consequently no by-passing has occurred.

4.4 Sewage Flows

Total dry weather flow to the WPCP is approximately 0.31 to 0.42 m^3/s (6 to 8 mgd) with a maximum of 0.60 m^3/s (11.5 mgd). About 72 percent of the total originates in the area served by the Front Street pumping station.

Extraneous flows, such as groundwater infiltration, represent about 18 percent of the total flow to the WPCP. The proportion from surface water inflow is estimated to be 12 percent. Thus, close to 30 percent of the total sewage flow is other than sanitary sewage [8].

The existence of extraneous flow to the sewer system is indicated by the difference between the mean daily per person sewage flow of 870 L (192 gallons) and the mean daily per person potable water pumpage of 630 L (139 gallons). During dry weather, a change in the level of the Moira River has been found to correlate with changes in the average daily sewage flow, a strong indication of infiltration [8]. Another indication of significant infiltration under dry weather conditions is high night-time flows with low levels of pollutants.

Major stormwater inflow occurs intermittently during rainfall and spring runoff. Historical data indicate significant increases in the flow to the WPCP during rainfall. On occasion, flows exceed the pumping capacity of the Front Street pumping station, resulting in high sewer levels and/or surcharging and occasional basement flooding. Under these conditions by-passing may occur.

4.5 The Belleville Water Pollution Control Plant

A schematic flow diagram of the Belleville WPCP is shown in Figure 8. The trunk sewers from the Front Street and Plant pumping stations each have separate grit removal tanks. Raw sewage from the two pumping stations is blended just ahead of the barminutors. Routine plant operation results in intermittent discharges of digester supernatant and

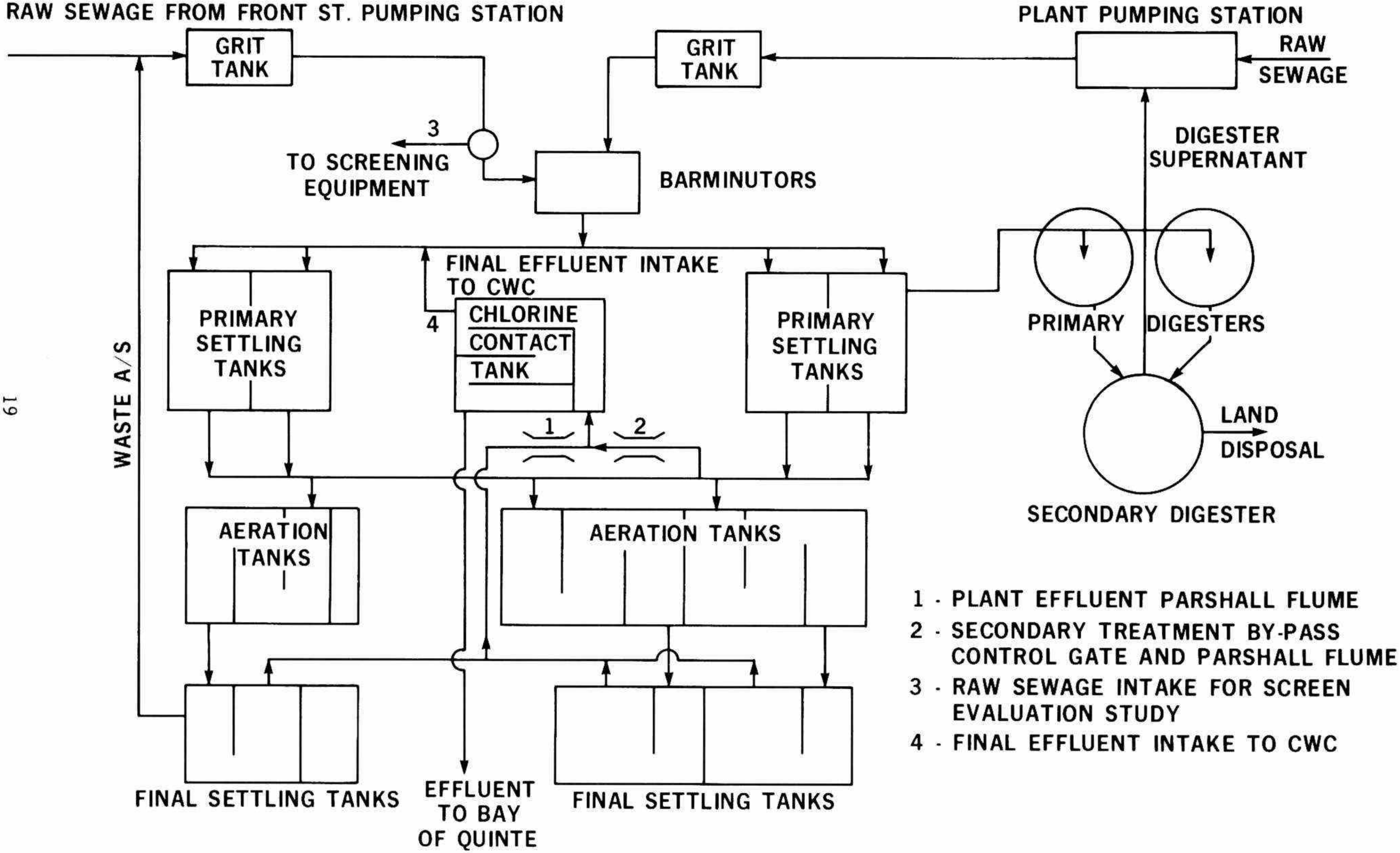


FIGURE 8. CITY OF BELLEVILLE WPCP

waste activated sludge upstream of the grit tanks. From the barminutors, the raw sewage flows by gravity to the four primary clarifiers. Primary sedimentation is followed by conventional activated sludge treatment, chlorination, and gravity discharge to the Bay of Quinte.

Secondary treatment capacity is limited to 0.6 m^3/s (11.5 mgd). Volumes in excess of this value and up to the total pumping station capacity of 1.16 m^3/s (22.25 mgd) receive primary treatment and chlorination.

A by-pass for raw sewage is located just ahead of the barminutor. Some by-passing, caused by blinding of the bar-screens, was observed during severe storm events. By-passing of secondary treatment is accomplished by a gate downstream from the primary clarifiers. This gate, which is opened automatically at preset flows, directs primary effluent to the chlorine contact tank.

The Plant and Front Street pumping stations have flow metering devices with the flow recorders located at the WPCP. However, the metering device at the Front Street station has been out of order for a number of years and direct flow data from this location were not available during the study. The WPCP final effluent flow is metered and recorded continuously. The secondary by-pass flow rate is also metered and recorded.

5 EQUIPMENT AND PROCEDURES

The experimental screening facilities were set up at the Belleville WPCP as shown in Figure 9. The area selected allowed easy access to degritted raw sewage or final effluent. Raw sewage was pumped independently to each of the screens under study. All process effluents, including sludges, were discharged to the header channel feeding the primary clarifiers. With the exception of the CWC, which was enclosed by a non-winterized wooden building, all devices were exposed to the elements. Screen operation was discontinued during the winter months.

5.1 Equipment

5.1.1 Centrifugal wastewater concentrator

A photograph of the CWC prior to startup is shown in Figure 10. The 1.5-m (60-inch) diameter unit had a rated hydraulic capacity of approximately 37 to 45 L/s (500 to 600 gal/min). The rotating screen cage was driven by a 3.7-kW (5-hp) induction motor through an overhead drive system which was isolated physically from the sewage flows. A single control panel allowed either manual or automatic screen operation. Counters on the control panel recorded accumulated screen operating time and backwash time.

Influent was pumped to the unit by one to two 30-kW (40-hp) Marlow self-priming, centrifugal pumps (IPT Fluid Handling, Guelph, Ontario) via 200-mm (8-inch) PVC piping. The screened effluent, or centrate, was collected in an annular chamber and flowed by gravity to a flotation cell located directly below the CWC. Between five and 30 percent of the incoming flow, referred to as concentrate, dropped down the inside of the screens into a receiving tank located below the unit.

The 1.5-m (60-inch) diameter screen cage featured two rows of 36 screen panels. Screen media for the Belleville application was 165-mesh, type 316 stainless steel, tensile bolting cloth (105-micrometre aperture with 47 percent open area). Leakage between the screen cage and screen panels was prevented by either slip-on or permanently attached gaskets around the perimeter of each panel. The unit had a total screening area of 2.0 m^2 (22 ft^2).

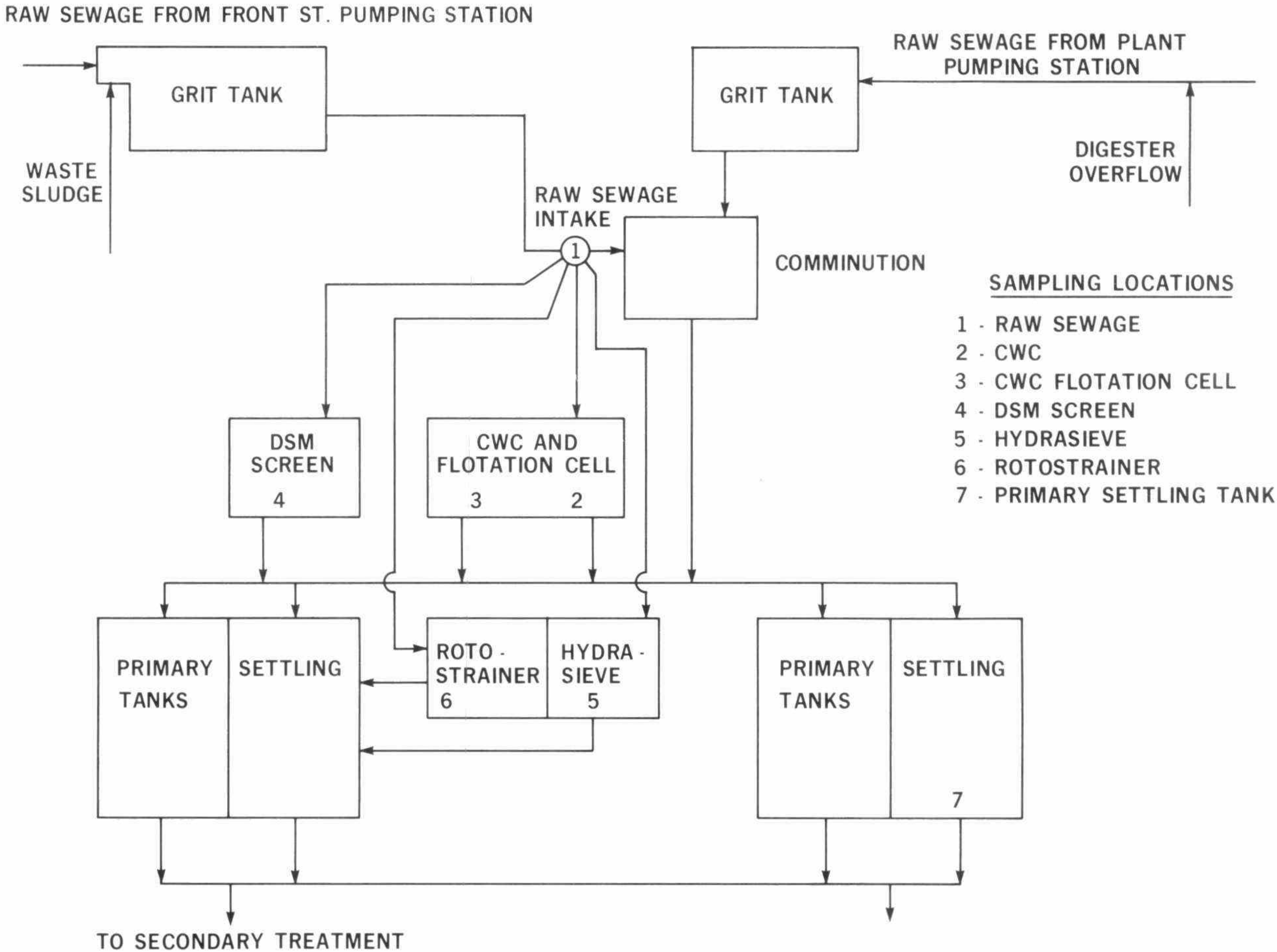


FIGURE 9. LAYOUT OF SCREENING FACILITIES AT THE BELLEVILLE WPCP

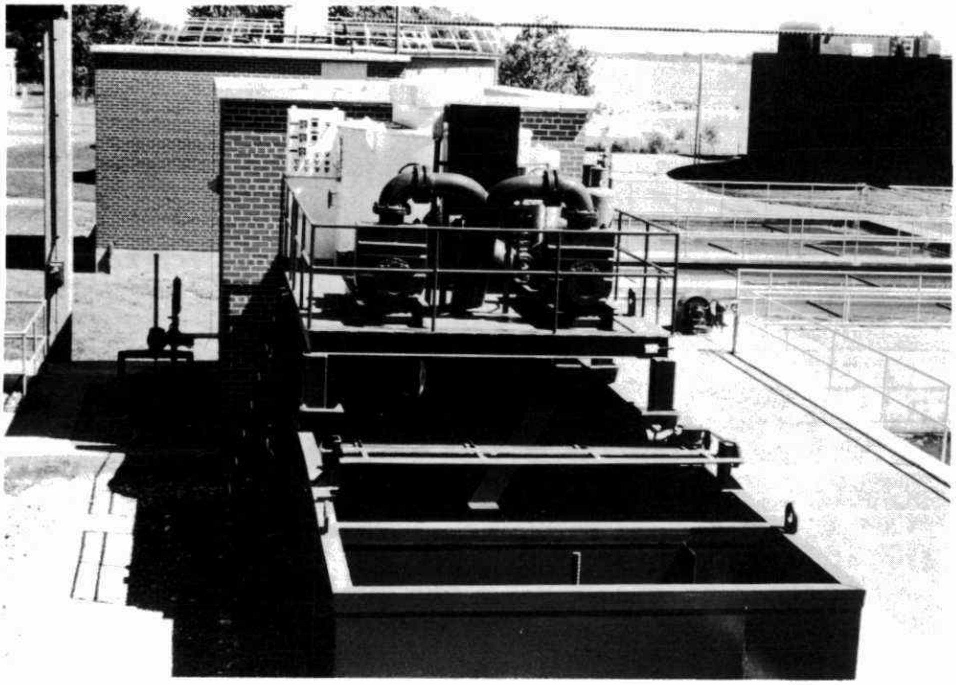


FIGURE 10. TOP VIEW OF CWC WITH FLOTATION CELL BEFORE ERECTION OF BUILDING

The major material of construction for the CWC was epoxy-coated mild steel. The screen cloth and spray nozzles were of 316 stainless steel. Pump suction and discharge piping was of 200-mm (8-inch) and 300-mm (12-inch) diameter PVC, respectively.

Essential auxiliary equipment included the built-in automated screen cleaning system. Cleaning was initiated either at a preset time interval or by a minimum hydraulic flow split. In the latter case a float-switch located in the concentrate tank was activated when the concentrate flow rate reached 30 percent of the influent flow rate. Because the raw sewage or stormwater often contained industrial oil and grease, a solution of hot water at 70°C (160°F) containing a suitable detergent or degreasing agent was needed for screen cleaning. The washwater was heated using two propane-fueled 180-L (40-gallon) water heaters connected in series. The detergent or solvent was diluted in-line by means of eductors. When needed, washwater from a booster pump was sprayed in sequence from the outside and inside of the screen cage onto the rotating screens at a pressure of 550 kPa (80 psig) and a flow rate of 0.5 L/s (6.2 gal/min). During the screening process, a continuous cold

water backwash spray from the outside of the screen cage was in operation at a pressure of 830 kPa (120 psig) and a flow rate of 0.9 L/s (11.5 gal/min). The source of cold backwash water was final effluent that had been strained through a Y-strainer with 1.2-mm (3/64-inch) perforations.

The flotation cell was designed to remove additional pollutants from the centrate by utilizing the air entrained during the screening process. The cell consisted of a large rectangular tank, active area 3.4 m x 6.4 m (11 ft x 21 ft), which was equipped with a rotating paddle to skim floating scum into a trough with an exit pipe.

The stainless steel-tensile bolting cloth media for final effluent polishing had a 44-micrometre (325-mesh) aperture. Effluent for this part of the study was chlorinated final effluent taken from the chlorine contact tank as shown in Figure 8.

A screening cycle for the CWC consisted of the following four sequential operations:

1) Wastewater was pumped, to the unit at a constant flow rate until the concentrate portion reached about 30 percent of the influent volume. This period might last from five to 20 minutes depending upon the characteristics of the raw sewage. During this stage continuous cold water backwash was supplied.
2) When the concentrate volume had reached a preset fraction of the influent flow rate, the continuous cold water backwash was stopped, the influent pump shut off, and a cleaning cycle initiated.
3) During the cleaning cycle the screen cage continued to revolve at 60 rpm while spray nozzles located outside the screens dislodged solids and grease back into the concentrate for 15 seconds. This was immediately followed by a 15-second period during which the screens were sprayed from the inside. In each case hot water with a proprietary cleaning agent (ZEP* - which contains o-dichloro benzene and cresylic acid) was used. This washing process was intended to restore the original hydraulic capacity.
4) Following cleaning, the influent pump and cold water backwash came on automatically, and the operating cycle was repeated.

---

*ZEP Manufacturing Co., Montréal, Québec.

Flow measurement devices were built into the discharge sections of the flotation cell and concentrate tanks. They consisted of a 0.9-m (3-ft) wide rectangular weir and a 45° v-notch weir, respectively, each fitted with a staff gauge. During the latter portion of the study centrate flow and screen cycle time were continuously monitored and recorded with the aide of a Silometer (capacitance) level sensing device which was mounted near the staff gauge ahead of the rectangular weir.

Centrate and concentrate samples could be taken immediately downstream of each of the two discharge ports from the screen. Flotation cell effluent was sampled at the rectangular weir. Raw sewage samples could be taken at the pump suction intake or from the headbox of one of the other operating screens.

Although the CWC normally was started and shut down manually, it was possible to have it on active standby for automatic startup and shutdown during storm events as required by the flows. For this purpose mercury float switches were installed in the plant secondary effluent and by-pass Parshall flumes. By-pass activity, initiated when secondary plant effluent flow rates exceeded 0.60 m^3/s (11.5 mgd) would start the unit and keep it in operation until the secondary effluent flow rate dropped to 0.42 m^3/s (8.0 mgd).

5.1.2 DSM screen

The DSM screen evaluated at Belleville was a 0.61-m (24-inch) wide unit. An overall view of the installation is shown in Figure 11. Although built especially for research studies, it was identical in design to commercial units. Screen plate size was 0.61 m (24 inches) by 1.60 m (63 inches), providing a total screen area of 0.98 m^2 (10.5 ft^2). The unit was supplied with screen plates having 88, 150, 305, and 1500-micrometre apertures. Rated hydraulic capacity for the unit with the 305-micrometre aperture screen plate was in the order 15 L/s (200 gpm).

Raw sewage was pumped by a 3.7-kW (5-hp) submersible Flygt* pump via 100-mm (4-inch) diameter flexible hose and PVC piping to the screen feed chamber. It then overflowed the parabolic-shaped weir onto the screen surface. Oversize solids (screen rejects) were discharged at the bottom. Screened effluent, which contained undersized material that

*Flygt Canada Ltd., Dorval, Québec.

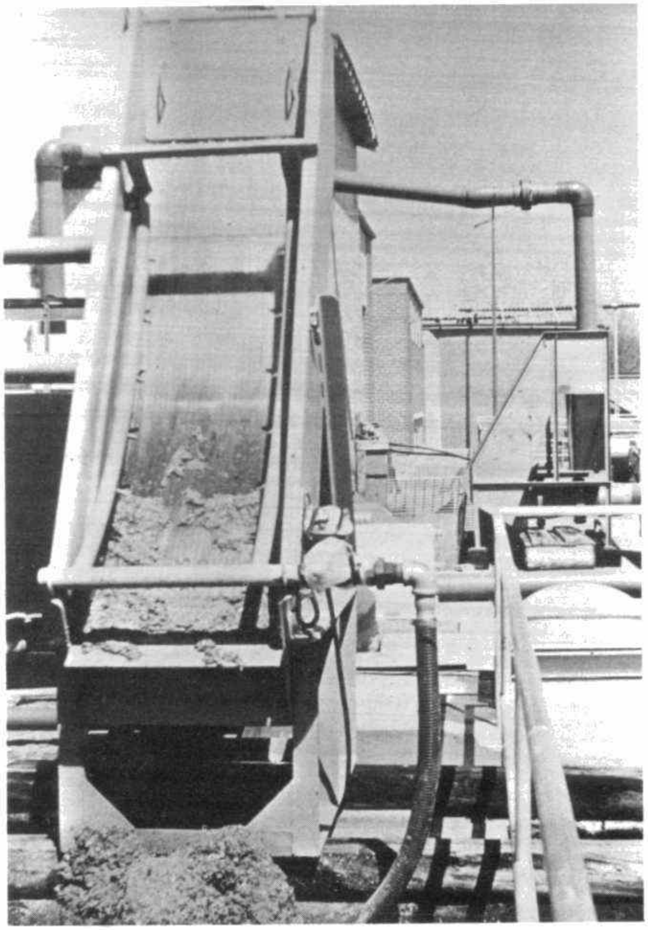


FIGURE 11. FRONT VIEW OF DSM SCREEN SHOWING TWIN SPRAY HEADERS - BAUER HYDRASIEVE IN BACKGROUND

passed through the screen, was discharged via a 150-mm (6-inch) diameter rear outlet pipe. At a later stage of the study, the DSM screen was used briefly as a thickening device for CWC concentrate. A 3.7-kW (5-hp) feed pump with a gasoline engine that delivered a maximum of 8.3 L/s (110 gal/min) was used during this test.

Two automated cleaning systems were used with the DSM screen. Initially the unit was furnished with twin spray headers (Figure 11) which could be operated on a timed cycle. While the sprays were on raw sewage flow was automatically turned off. This system was later replaced with a continuous mechanical reciprocating brush that extended the full length of the screen and travelled back and forth across its width (Figure 12). The brush was driven by a 0.4-kW (0.5-hp) electric motor.

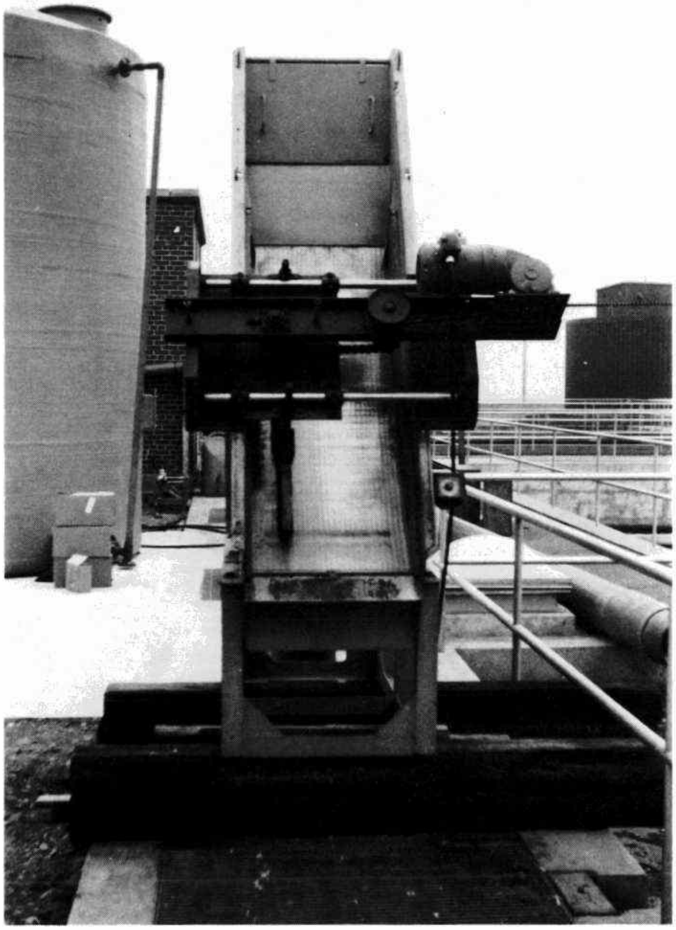


FIGURE 12. FRONT VIEW OF DSM SCREEN SHOWING RECIPROCATING MECHANICAL BRUSH

Sewage flow was measured by collecting the screen effluent in a 230-L (50-gallon) vessel. Raw sewage and screen effluent samples were taken from the screen headbox and discharge pipe, respectively. On occasion, screen rejects were collected together with all free water spilling across the screen to obtain an indication of the true solids concentration of the sludge. The screen frame assembly was made of painted malleable iron, and the screen plate was of 316 stainless steel.

5.1.3 Hydrasieve

The Hydrasieve was similar to the DSM screen. The unit evaluated had a 1.8-m (72-inch) by 1.4-m (54-inch) screen plate, providing a total screen area of 2.5 m^2 (27 ft^2). No automated screen cleaning device was available. The three screen plates available had 254-, 762- and 1524-micrometre apertures with rated hydraulic capabilities of approximately 0.01 to 0.07 m^3/s (140 to 870 gpm).

Raw sewage was pumped to this screen by a 30-kW (40-hp), self-priming, Marlow centrifugal pump via 200-mm (8-inch) diameter PVC piping. The sewage was pumped to a headbox from which it overflowed onto the screen surface. Feed piping to the unit was arranged in such a way that the rectangular weir of the CWC flotation cell could be utilized for flow measurement. Oversize solids were discharged at the bottom of the screen plate together with some free water. Screened effluent was discharged via a 360-mm (14-inch) diameter rear outlet. The screen plate and support structure were fabricated from 316 stainless steel.

5.1.4 Rotostrainer

The Rotostrainer evaluated had a 1.5-m (60-inch) long, 0.64-m (25-inch) diameter screen cylinder with a total area of 3.04 m^2 (32.8 ft^2). The three screen cylinders supplied had 250-, 500-, and 750-micrometre apertures. Nominal rated capacity for a screen cylinder with 500-micrometre apertures was approximately 60 L/s (800 gpm). The installed unit is shown in Figure 13.

The screen cylinder was driven by a manually-adjusted variable speed Reeves* drive which was powered by a 0.37-kW (0.5-hp) motor that provided cylinder speeds of one to ten rpm. The cylinder support structure incorporated a feed chamber and discharge tank. Neoprene seals along the overflow lip to the screen cylinder and along the cylinder sides confined the raw sewage within the headbox and above the effective screening portion of the cylinder. The unit had optional inside backwash sprays that were used only for cleanup prior to shutdown.

Raw sewage was pumped by a 30-kW (40-hp) self-priming Marlow centrifugal pump via 200-mm (8-inch) PVC piping to the headbox from which it flowed onto the rotating screen. Oversize solids travelled on the

---

*Reliance Electric Ltd., Stratford, Ontario

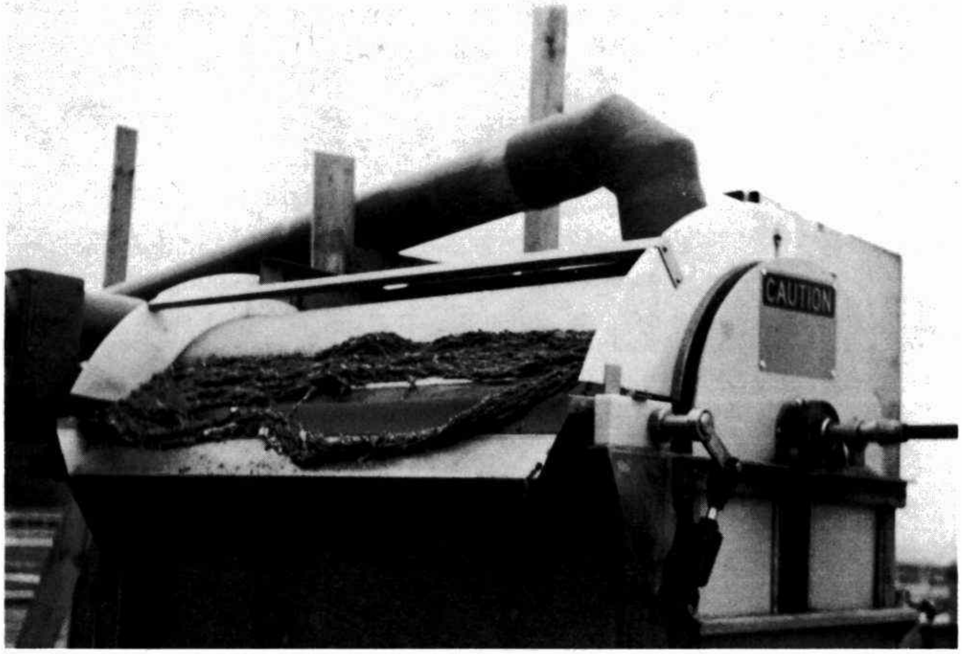


FIGURE 13. ROTOSTRAINER SHOWING SOLIDS REMOVAL BY SCRAPER (DOCTOR) BLADE

outer screen surface until scraped off by the doctor blade. Suspended matter that was wedged in the screen wire was removed by the effluent as it was discharged from the inside of the cylinder. Before discharge the screened effluent passed through an 810-L (180-gallon) tank used for flow measurements.

Material for the screen cylinder and frame assembly was 304 stainless steel.

5.2 Operations

5.2.1 Start-up and debugging

The sequence of start-up, debugging, and modification of the major equipment is shown in Table 2. The dates of shut-down and/or equipment removal are also shown.

Screening devices were installed as received and necessary modifications were made as components became available. As indicated in the table, the modifications required for the different units varied widely.

A major problem, which became apparent as soon as testing began, was the almost constant presence of digester overflow (sludge) or waste activated sludge in the raw sewage. When present, the sludges caused

TABLE 2. SEQUENCE OF START-UP, MODIFICATIONS, AND SHUT-DOWN OF MAJOR EQUIPMENT 1973 (CWC delivered and installed)

April 1974	CWC: startup
June 11, 1974	Relocation of CWC raw sewage intake and commencement of equipment evaluation
August 29, 1974	Hydrasieve: start-up with 0.060-inch screen plate
September 12, 1974	CWC: continuous cold water backwash installed
September 17, 1974	Hydrasieve: 0.25-mm screen plate installed
October 10, 1974	Hydrasieve: "Water-fall" feed plate installed
November 6, 1974	Hydrasieve: 0.75-mm screen plate installed
November 25, 1975	CWC: shut-down for winter of 1974-75
November 27, 1974	Hydrasieve: "Water-fall" feed plate removed
December 20, 1974	Hydrasieve shut-down for winter of 1974-75
March 18, 1975	CWC: modification of screen cleaning system
April 24, 1975	CWC: start-up
April 24, 1975	Hydrasieve: start-up
May 1, 1975	DSM Screen: start-up with spray cleaning system
June 19, 1975	Hydrasieve: shut-down for removal
July 11, 1975	CWC: shut-down for removal
August 19, 1975	Rotostrainer: start-up with 500-micrometre screen
August 19, 1975	DSM Screen: mechanical brush installed
October 17, 1975	Rotostrainer: 250-micrometre screen installed
October 28, 1975	DSM Screen: shut-down for removal
November 6, 1975	Rotostrainer: shut-down for removal

rapid blinding of the screens. Also, the sludge caused suspended solids levels in the raw sewage to be up to ten-fold above normal levels, and very little sludge separation occurred across the screening media, even when feed rates were drastically reduced to minimize blinding.

Since sludge from the digesters was being blended with the raw sewage from the wet well of the plant pumping station, the suction intake point for raw sewage was relocated, and subsequently only sewage originating from the Front Street pumping station was fed to the screening devices. The problem of waste activated sludge which was returned upstream of the grit tank serving the Front Street trunk sewer remained. Since it was not possible to eliminate this problem without major piping changes within the WPCP, it was decided that the screening devices would not be operated while sludge was being wasted. Plant personnel cooperated by wasting sludge only during early mornings and in the evening. The WPCP staff also deferred wasting of sludge during storm events in order to allow screen evaluation to continue. Although the original plan for the study provided for simultaneous comparison of screening with primary sedimentation, this portion of the study had to be abandoned because the raw sewage fed to the primary clarifiers still contained waste activated or digested sludge and was, therefore, not comparable to the raw sewage pumped to the screens.

Initial operating problems encountered with each screen were mainly related to cleaning. A description of difficulties encountered and steps taken to resolve them can be found in Appendix A. The cleaning systems for the CWC and DSM screen were rebuilt during the study. The blinding problem with the Hydrasieve was never resolved satisfactorily.

5.2.2 Routine operation and maintenance

The screens were operated daily during regular working hours unless modifications or maintenance were being carried out. If a storm started during working hours, operation was continued until the end of the event. If a storm began outside working hours, the screens were started during the ongoing event and operated until it ended.

5.2.2.1 Centrifugal wastewater concentrator. Routine operation refers to periods on manual or automatic control when all operating problems had been solved, the screen cleaning system was performing effectively, and

flow metering devices for centrate and concentrate were available. Start-up, timed operating sequences, and shut-down of the CWC, including feed pumps, screen cage, and backwash systems, were performed using the master control panel according to the supplier's manual.

Before operation could begin, hot and cold service water and the chemical degreasing agent had to be available. The screen drive was then started followed by the feed pump. After the unit had been in operation for about five minutes, sampling and the taking of flow measurements commenced. Flow was normally set at the maximum possible, and duration of the screening cycle was set to maintain the hydraulic split within reasonable limits, e.g., an average centrate to concentrate ratio of 70:30 for the overall cycle. Sampling was always performed at least one minute after screen cleaning to avoid contamination of the sample by the chemical degreaser. No attempt was made to evaluate screen performance as a function of time within a screening cycle.

Operations under wet and dry weather conditions were identical except for the duration of the screening cycle. Under wet weather conditions screen operation was limited to a five-minute cycle during the "first flush" (see Section 6.12 for explanation of this term) and then increased to a maximum of 20 minutes. For dry weather operation the screening cycle was between five and 20 minutes depending on the raw sewage characteristics.

Screen operation during the final effluent polishing phase could be considered completely automated with the installed equipment and controls. During this stage all operating variables were fixed, including the screening cycle which was arbitrarily set at 20 minutes.

Regular maintenance included inspection of the screen panels on a weekly basis or after each storm event depending on operation. Occasional manual cleaning of the screen with engine cleaner was necessary. Although inspection and lubrication of the equipment was carried out on a routine basis, according to the operating manual, the effort involved was minimal. Spare parts stocked included screen panels and solenoid valve replacement kits for the backwash system. An inventory of chemical screen degreasers and propane was also kept on hand.

Final effluent polishing was essentially maintenance free during the three-week study period, and no manual screen cleaning was required.

5.2.2.2 DSM screen. Starting the DSM screen required activation of the feed pump and mechanical brush. Screen operation was then continuous, screen cleaning occurring simultaneously. The flow rate to the unit was constant at all times. Little maintenance was required aside from general cleanup after a shut-down to prevent caking-on of sludge, and manual cleaning about every 12 to 24 hours of operation with the 305-micrometre screen plate, particularly on the underside of the screen panel. The 150-micrometre screen plate required manual cleaning every 30 minutes.

5.2.2.3 Hydrasieve. Starting the Hydrasieve required starting the feed pump. Screen cleaning was done manually by brushing or hosing down as needed to maintain operation. This was necessary every hour for the screen plate with a 254-micrometre aperture and once every eight hours for the 762-micrometre plate. The 1524-micrometre plate was washed down only as needed for housekeeping purposes.

5.2.2.4 Rotostrainer. To start the Rotostrainer the motor driving the screen was activated and the feed pump was put into operation. The rotational speed of the cylinder was then adjusted to the minimum value possible without hydraulic overload at a constant feed rate. Occasionally the doctor blade had to be adjusted to obtain good contact with the rotating cylinder. As with the other screening devices, built-up solids had to be washed off prior to shut-down to prevent caking. Aside from the above maintenance operations, only minor and periodic lubrication and general inspection was required, as specified in the manufacturer's operating manual.

5.3 Sampling and Analysis

During dry weather operation, flows were sampled hourly. If a storm event occurred during regular working hours the sampling frequency was increased. If a storm event occurred after regular working hours, the delay in equipment start-up meant that sampling normally did not commence until the by-pass event was already at its peak. Sampling then continued for the duration of the by-pass event. Because of the unreliability of available automatic sampling equipment all sampling was manual. Grab

samples were taken from the raw combined sewage after grit removal, from the screened effluent from each unit in operation, and from the CWC-concentrate and flotation cell effluent. Because the suction point was identical for all screens, only one raw sewage sample was taken with each set of samples, normally from the influent headbox of one operational screen. Sampling intervals were usually 15, 30, or 60 minutes but they could be affected or interrupted by equipment operating problems; this was particularly true during the 1974 operating period. Locations of all sampling points are shown in Figure 9.

The parameters monitored were settleable solids, suspended and volatile suspended solids, BOD_5, COD, nutrients, ether extractables, and bacteria.

Samples were shipped daily by express to the Ministry of the Environment Laboratories in Toronto and analyzed according to the standard laboratory methods [9]. An exception was the analysis for settleable solids which was performed on-site using the standard Imhoff cone method.

6 RESULTS - WET WEATHER OPERATION

6.1 Definition and Characteristics of Storm Flows

6.1.1 Storm event

A method of identifying the beginning and end of storm flows at the WPCP was required for data analysis because the various screening devices were often already operating on dry weather flows when a storm began. Storm flows were considered to begin when precipitation produced a rise in raw sewage flow rates at the WPCP above the normal diurnal variations. A storm event was considered to have ended when the flow rates returned to normal dry weather values.

Since project staff had to travel to the WPCP to start the screens for storms that began outside normal working hours, reasonably complete monitoring was achieved for only a few of the longer storms that began outside working hours.

The 1974/75 period was unusually dry, and only 14 storm events were monitored, as shown in Table 3. Ten of these storms occurred between June and December, 1974; only four occurred between May and September, 1975.

6.1.2 First flush

Raw sewage quality varied widely during individual storm events and from one event to another. Observations and analyses of samples suggested that as far as screen performance was concerned there were two characteristic types or portions of storm events. Since only one type resulted in high concentrations of suspended matter, a parameter critical to screen performance, it was desirable to distinguish between the two types of events.

A storm event, or some portion of a storm event, was considered as having a "first flush" if high flow rates at the WPCP were accompanied by suspended solids concentrations in excess of 300 mg/L. This level is well above the 1974 dry weather average concentration of suspended solids of 140 mg/L. Storms resulting in suspended solids levels less than 300 mg/L were considered to be "non-first flush". In storms having a first flush, the suspended solids concentrations during later, "post-flush", portions of the storm sometimes fell below 300 mg/L. Since few post-flush samples were taken in any one storm, they were not used to evaluate screen performance.

TABLE 3. RAW SEWAGE CHARACTERISTICS - ARITHMETIC MEANS OF CONCENTRATIONS OF PARAMETERS MONITORED DURING INDIVIDUAL STORM EVENTS

	SS (mg/L)	VSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	Total P (mg/L)	Settleable Solids (mL/L)	Number* of samples
June 19/74**	510	223	115	--	16	5.1	7.5	2
July 23/74**	590	250	203	--	27	7.2	--	3
August 27/74	136	61	30	--	14	3.0	1.0	7
September 25/74	224	149	60	--	29	5.6	7.6	5
October 17/74	254	96	55	--	21	3.7	3.0	6
November 12/74**	335	113	126	383	21	5.4	3.8	4
November 13/74	205	101	130	218	17	4.9	2.3	4
November 20/74**	399	143	78	280	15	4.1	3.7	5
November 21/74	133	64	65	190	13	2.6	1.2	9
December 2/74**	332	155	117	387	25	5.6	3.9	3
May 30/75**	704	253	102	632	23	4.2	12.8	8
June 5/75**	646	222	108	485	20	4.6	9.0	7
July 9/75**	608	285	140	627	30	6.8	8.8	3
August 25/75**	576	202	75	415	19	4.5	5.3	17
First Flush								
Overall Mean	522	205	118	458	22	5.3	6.8	--
Maximum	704	285	203	632	30	7.2	12.8	--
Minimum	332	113	75	280	16	4.1	3.7	--
Non-First Flush								
Overall Mean	191	94	68	204	19	4.0	3.0	--
Maximum	254	149	130	218	29	5.6	7.6	--
Minimum	133	61	30	190	13	2.6	1.0	--

* Does not include settleable solids.
**Storm with first flush.

6.1.3 Characteristics of storm flows

The arithmetic means of the concentrations of SS, VSS, BOD_5, COD, TKN, total P, and settleable solids for all storm events monitored are shown in Table 3. The levels of all parameters except nutrients varied widely. Nine storms had first flush conditions.

Because the number of storms monitored was small, no detailed analysis of factors influencing raw sewage quality was attempted. However, on two occasions during November 1974 when storm events occurred on successive days, the first storm produced a first flush condition but the second did not. Table 3 also shows, for each parameter monitored, the ranges and overall means obtained for storms with and without a first flush. Even when the data are grouped into first flush and non-first flush events mean values in each group vary widely, nutrient parameters again excepted.

Figures 14 and 15 show probability plots for SS, VSS, BOD_5, and settleable solids during first and non-first flush storms. The data shown are the arithmetic means for the individual storm events of Table 3. For all parameters except possibly settleable solids a linear fit appears appropriate, i.e., the means are approximately normally distributed. The steeper slope of suspended solids concentrations during first flush conditions (Figure 14) indicates the greater variability in this parameter during this type of event.

First flush conditions at Belleville generally coincided with the initial rise of flow rates and continued for periods of 0.5 to 4 hours. Elevated flows and by-passing of secondary treatment also occurred during non-first flush storms. Figures 16 and 17 illustrate the variations in flow and pollutant concentrations in the combined sewage from the Front Street pumping station during two storms - one with and one without a first flush. In Figure 16, the peak concentrations of suspended solids occur well before the maximum flow at the WPCP. Suspended solids concentrations are above 300 mg/L for most of the storm. The variation in total flow rate to the WPCP closely follows the trend in flows from the Front Street pumping station. Short term fluctuations in the Front Street flows result from variations in the number of pumps in service at the

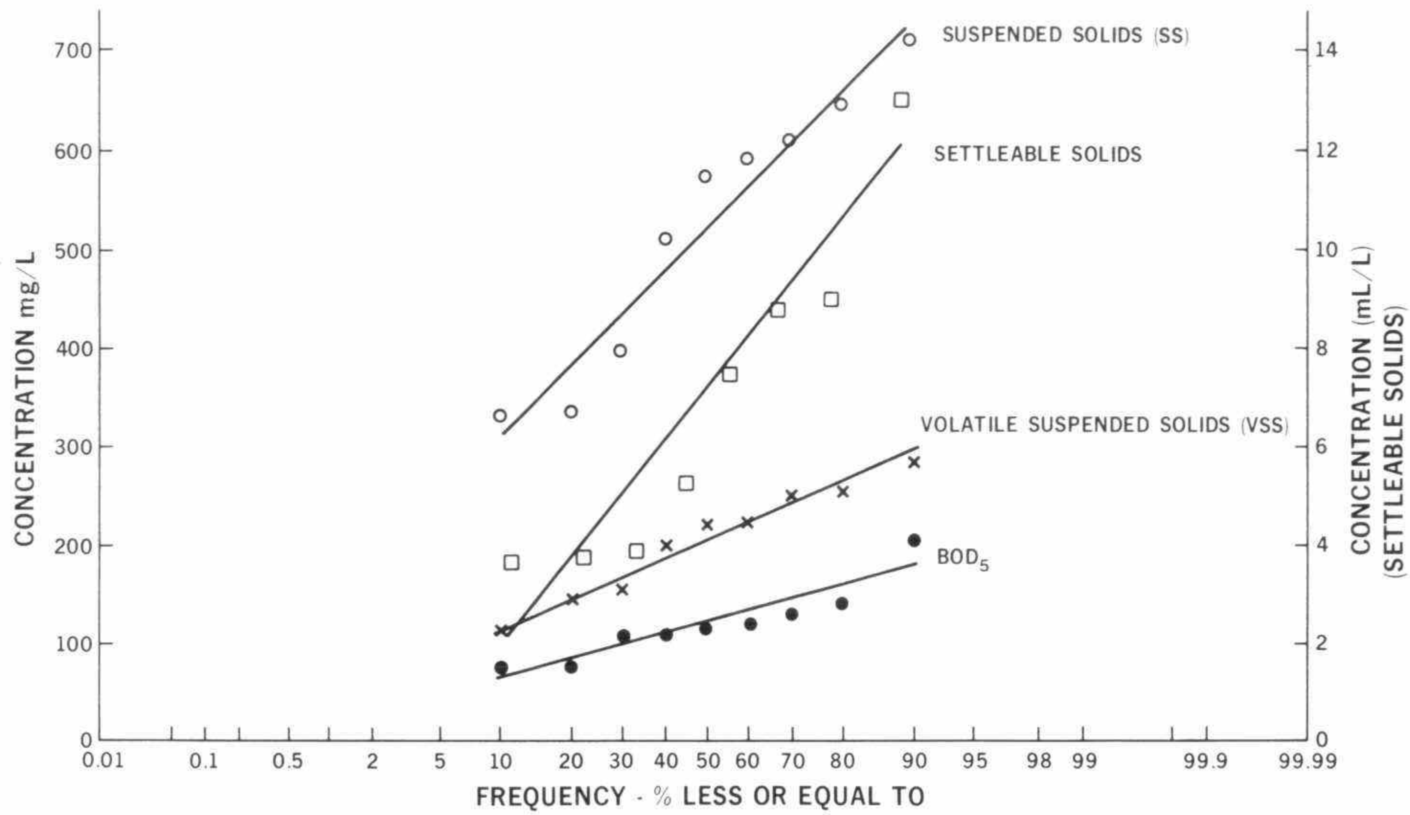


FIGURE 14. RAW SEWAGE CONCENTRATION PROFILE FOR FIRST FLUSH PORTIONS OF STORM EVENTS

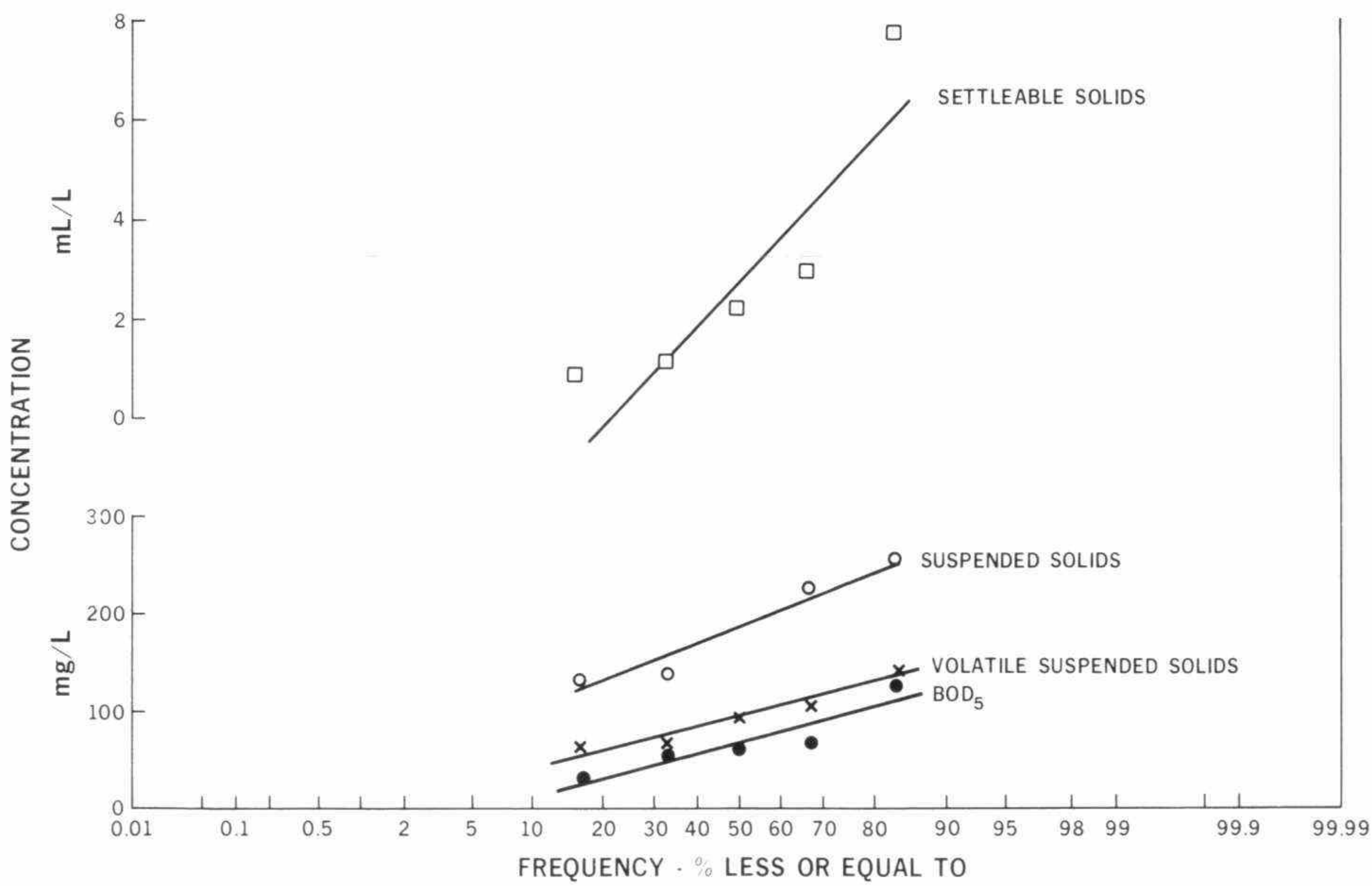


FIGURE 15. RAW SEWAGE CONCENTRATION PROFILE FOR STORM EVENTS WITHOUT A FIRST FLUSH

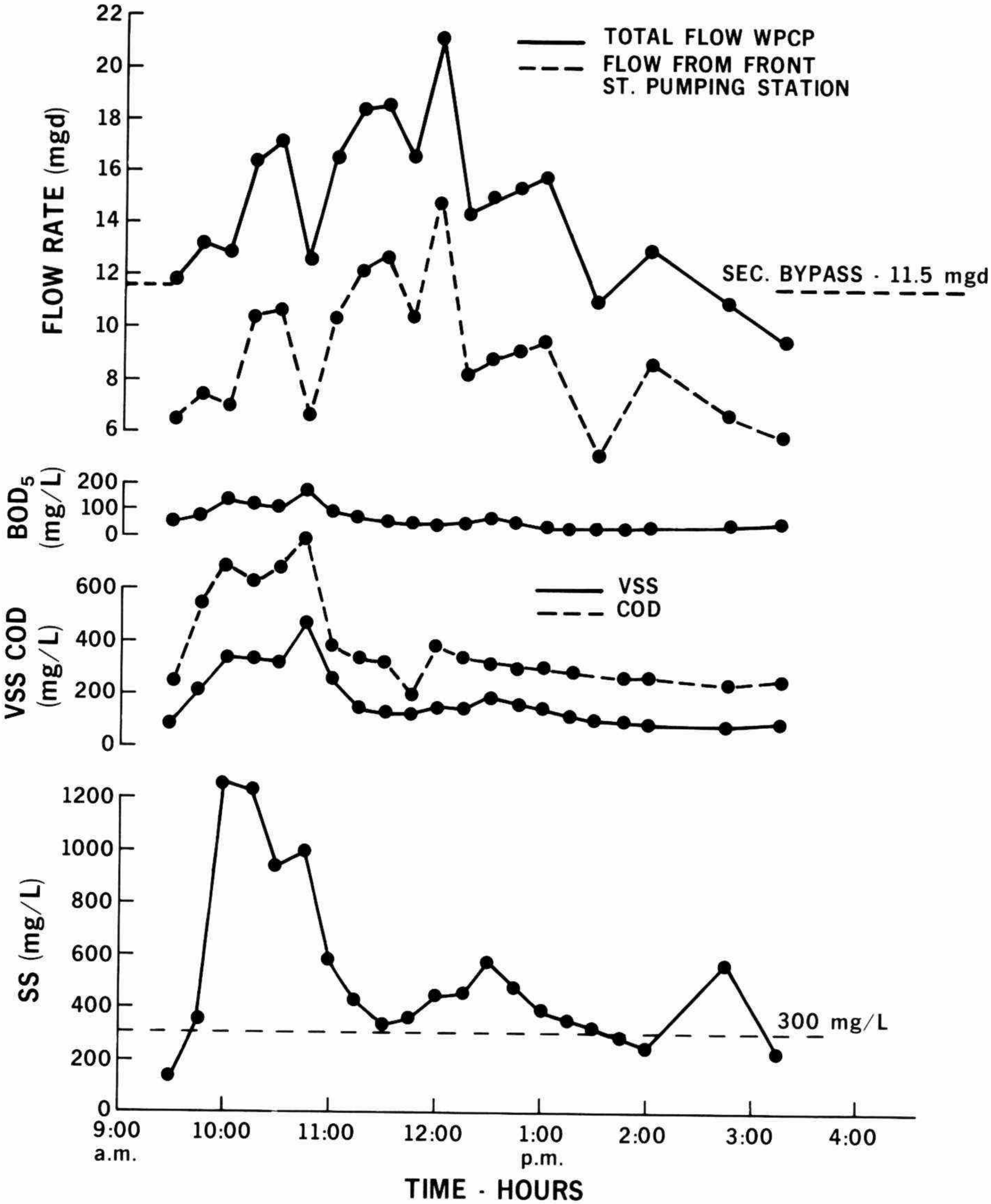


FIGURE 16. CONCENTRATION AND HYDRAULIC FLOW PROFILES OF RAW SEWAGE DURING STORM EVENT HAVING A FIRST FLUSH - AUGUST 25, 1975

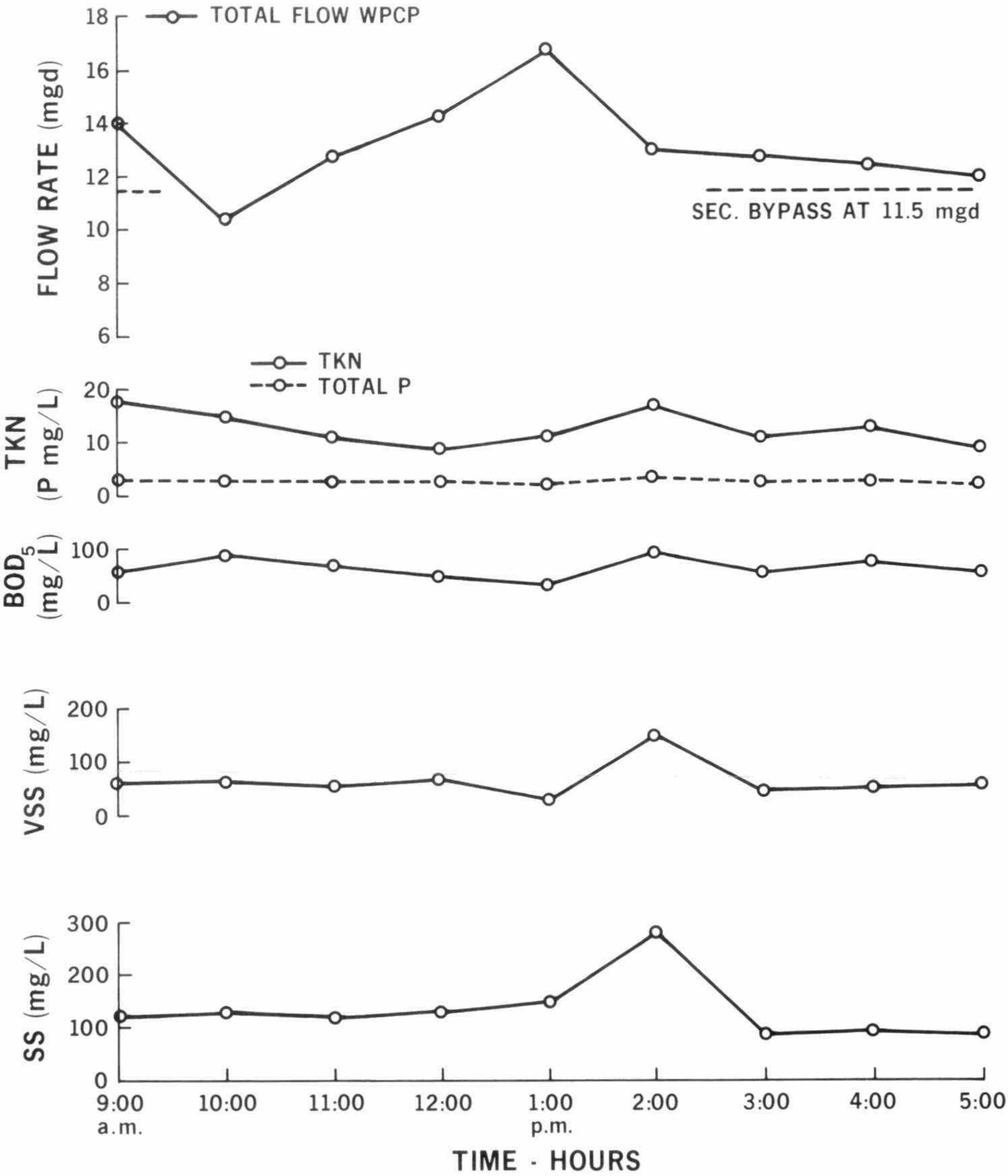


FIGURE 17. CONCENTRATION AND HYDRAULIC FLOW PROFILES OF RAW SEWAGE DURING STORM EVENT WITHOUT A FIRST FLUSH - NOVEMBER 21, 1974

pumping station. In Figure 17 the flow rate data have been adjusted to eliminate the effect of pump cycling. In this non-first flush storm event, the values for suspended solids and other parameters show relatively small peaks. The threshold flow at which by-passing of secondary treatment occurs is indicated in both figures.

6.1.4 Oil and grease

Data on concentrations of solvent extractable materials (oil and grease) during wet weather flows are included with the dry weather results in Appendix B. Values up to 95 mg/L were found during storm events, but there are insufficient data to justify separate presentation. Since it was believed that solvent extractables were mainly responsible for "progressive" or "irreversible" screen blinding, analyses for this parameter were made on accumulated screen panel residues. The residues had the characteristics of paraffinic-based SAE 30 lubricating oil. It was noted that, at the time of the study, Belleville did not have a readily available disposal site for waste oil.

6.2 Centrifugal Wastewater Concentrator

6.2.1 Hydraulic performance

The actual or average hydraulic capacity of the CWC is always lower than the nominal capacity because of the backwash time within a screening cycle. At Belleville, a period of 30 seconds was needed for screen backwash, and to maintain an acceptable hydraulic split the operating cycle time was generally in the range of five to ten minutes. This produced actual capacities five to ten percent below nominal capacity.

The hydraulic split, defined as the ratio of centrate to concentrate, determines the volume of concentrate, which requires further treatment. The relative fraction of concentrate increased progressively during each screening cycle due to "temporary" blinding. Over an extended period of operation, the most favourable split, obtainable at the start of a cycle, also declined gradually due to "permanent" blinding. Consequently, a maximum allowable concentrate fraction of 30 percent was selected beyond which screen operation was terminated. To eliminate "temporary" blinding, automatic screen backwashing was initiated. To eliminate "permanent"

blinding, it was necessary to take the screen out of service for manual cleaning with a degreasing agent.

In practice, a 70/30 split could be maintained at cycle times of about five minutes under first flush conditions and ten minutes for less severe storm conditions. When screening raw sewage, the hydraulic split started to deteriorate irreversibly after a few cycles, with accelerated deterioration in the presence of slugs of oil and grease. In 1974, operational problems with the screen resulted in considerable periods in which splits much lower than 70/30 had to be accepted in order to maintain screen operation.

Typical flow rates, hydraulic splits, and cycle times for the 1.5-m (60-inch) diameter CWC with 105-micrometre screen apertures are summarized in Table 4. The wide variations in feed rates, hydraulic splits, and cycle times reflect the varying severity of storm events under first flush conditions and the inadequacy of the screen backwash system prior to modifications.

Nominal flow rates under first flush conditions were generally of the order 2.5 $m^3/m^2 \cdot min$ (51 gpm/ft^2) or less, depending on the degree of intake line plugging. During post flush conditions nominal flow rates up to 4.6 $m^3/m^2 \cdot min$ (95 gpm/ft^2) were possible. Under first flush conditions, the hydraulic split deteriorated rapidly at flow rates greater than 3.0 $m^3/m^2 \cdot min$ (60 gpm/ft^2).

It can also be seen in Table 4 that after November 20, 1974, improved screen cleaning made operation more consistent and satisfactory. Additional improvements in the cleaning system could further improve the hydraulic split under first flush conditions. Due to continuous daytime dry weather operation the screen panels were not always as clean as desirable at the onset of a storm event, and the hydraulic split under first flush conditions was reduced to less than 70/30 even in 1975.

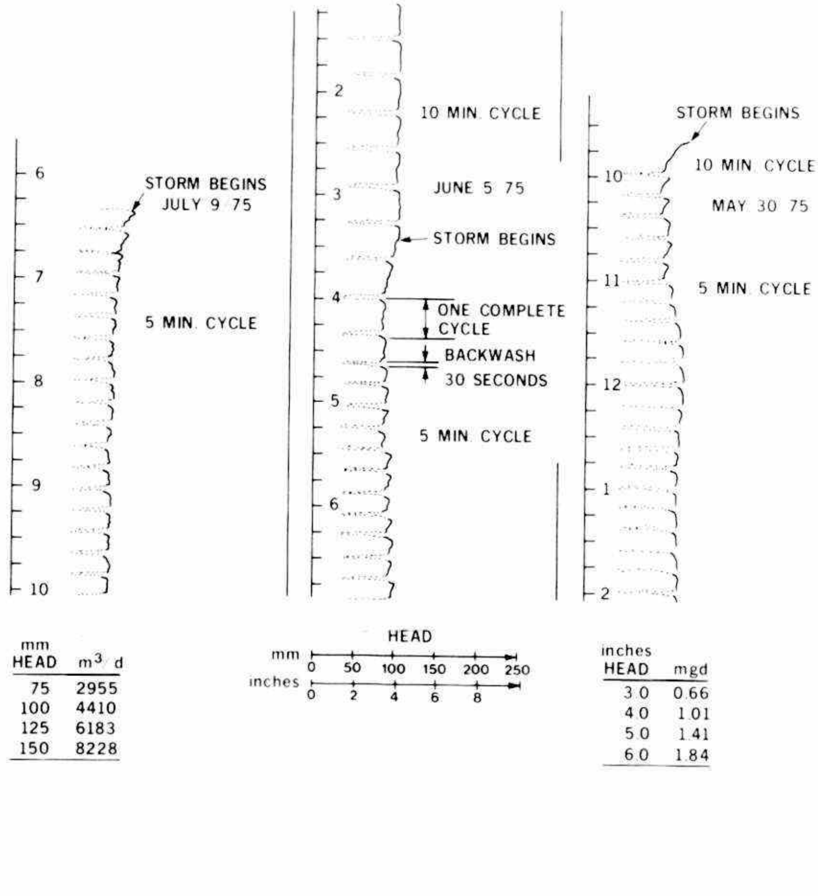
Figure 18 illustrates typical changes in the centrate flow rate and screen cycle time observed during three storm events with a first flush in 1975. The reductions in cycle time at the start of two of the storms are the result of operator action taken in order to maintain a reasonable split. Sudden deterioration and gradual recovery of centrate

TABLE 4. HYDRAULIC FLOWS, SPLITS, AND SCREENING CYCLES FOR CWC DURING STORM EVENTS

	Feed $m^3/m^2 \cdot min$ (gpm/ft^2)						
	Nominal*	Actual**	Split	Cycle Time (minutes)	Sets of Samples	Duration (h)	Precipitation (mm)
First Flush Conditions							
June 19/74	1.4 (28)	0.7 (14)	50/50	1	2	1	21
July 23/74	1.2 (25)	1.0 (21)	70/30	3	3	1	8
November 12/74	1.4 (28)	1.3 (27)	-	10	4	5	18
November 20/74	2.5 (51)	2.3 (46)	75/25	5	5	2	25
May 30/75	2.3 (47)	2.1 (42)	69/31	5	8	1.75	17
June 5/75	2.3 (47)	2.1 (42)	66/34	5	7	3	21
July 9/75	2.2 (44)	2.0 (40)	62/38	5	3	1	4
Non-First Flush Conditions							
August 27/74	3.0 (60)	2.8 (57)	82/18	10	7	6	41
September 25/74	2.0 (41)	1.9 (39)	75/25	10	5	4	6
October 17/74	2.2 (44)	1.4 (29)	70/30	1.5	6	2.5	11
November 13/74	2.2 (44)	2.1 (42)	-	10	4	3	8
November 21/74	2.5 (51)	2.3 (46)	74/26	5	9	8	9

* Flow rate to CWC.

**Screen capacity corrected for downtime, 30 seconds per cycle



mm HEAD	m^3/d
75	2955
100	4410
125	6183
150	8228

inches HEAD	mgd
3.0	0.66
4.0	1.01
5.0	1.41
6.0	1.84

FIGURE 18. CYCLE TIME AND CENTRATE FLOW FOR CWC DURING TYPICAL STORM EVENTS

flow, resulting from a decline and recovery in split, occurred to some extent in all three storms.

6.2.2 Pollutant removal efficiency

6.2.2.1 Concentration basis. Percentage pollutant removals for each storm event, based on concentration changes across the screen media, are shown in Table 5 for selected parameters. The values shown are averages of percentage removals derived from individual pairs of influent and centrate samples. Overall averages for each type of storm are also presented. The percentage removals of the parameters vary in different storm events. Removals of pollutants other than settleable matter were generally much higher during those storms with a first flush. However, high percentage removal efficiencies do not necessarily correspond to better centrate quality or to better segregation of influent pollutant mass into the concentrate as is discussed in Section 6.2.2.3.

Percentage removals were generally highest during May-July, 1974. Screen blinding, reduced capacity, and poorer hydraulic split were all experienced during this period because the backwash system was not working effectively. The higher removal efficiencies were probably the result of a reduction in the effective screen aperture due to partial blinding.

The average percentage removals of SS, VSS, BOD_5, and settleable solids during storms with a first flush are presented in Figure 19 in the form of probability plots. Each point in the figure represents the arithmetic mean of all data from a single storm event. The relatively steep slopes of the plots illustrate the wide variation in the data. Figure 20 is a similar plot for storms without a first flush. Because of the relative scarcity of storm-related data and the large variance in the probability plots, more detailed statistical analysis of the data was not attempted.

6.2.2.2 Mass basis. Mass flow rates of SS, VSS, and BOD_5 across the screen media were calculated for storm events that occurred after improvements to the backwash system had been made. Mass flow rates were established using the average arithmetic means of influent and centrate concentrations, and values for the hydraulic split and actual flow rate to the unit.

TABLE 5. PERFORMANCE OF CWC DURING STORM EVENTS - AVERAGE PERCENT REDUCTION PER EVENT (concentration basis)

Date	SS (mg/L)	VSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	Total P (mg/L)	Settleable Solids (mL/L)	Nominal Flow $m^3/m^2 \cdot min$ (gpm/ft^2)
1974								
June 19*	48.5	60.5	34.0	-	21.5	31.5	95	1.4 (28)
July 23*	44.7	44.3	30.3	-	16.3	23.0	-	1.2 (25)
August 27	11.4	17.6	0	-	1.0	4.6	99	3.0 (60)
September 25	20.0	28.4	6.4	-	3.0	3.4	77	2.0 (41)
October 17	20.0	28.0	7.0	-	5.0	7.0	90	2.2 (44)
November 12*	15.8	39.2	11.5	11.5	0	7.0	67	1.4 (28)
November 13	21.0	42.2	13.3	9.0	3.0	18.0	93	2.2 (44)
November 20*	23.8	38.0	24.6	23.0	10.0	16.0	85	2.5 (51)
November 21	22.0	26.6	6.0	11.0	7.0	7.0	97	2.5 (51)
1975								
May 30*	34.6	49.5	24.8	33.0	19.6	7.8	73	2.3 (47)
June 5*	31.1	41.1	17.6	25.0	20.0	14.3	73	2.3 (47)
July 9*	24.0	39.3	25.3	23.3	7.3	6.0	-	2.2 (44)
Average*	31.7	44.6	24.0	23.2	13.5	15.1	79	-
Minimum*	15.8	38.0	11.5	11.5	0	6.0	67	-
Maximum*	48.5	60.5	34.0	33.2	21.5	31.5	95	-
Average	18.9	28.5	6.4	10.0	3.8	8.0	91	-
Minimum	11.4	17.6	0	9.0	1.0	3.4	77	-
Maximum	22.0	42.0	13.0	11.0	7.0	18.0	99	-

*Storm with first flush condition

% Reduction (concentration basis) x Centrate Fraction = Mass Removal

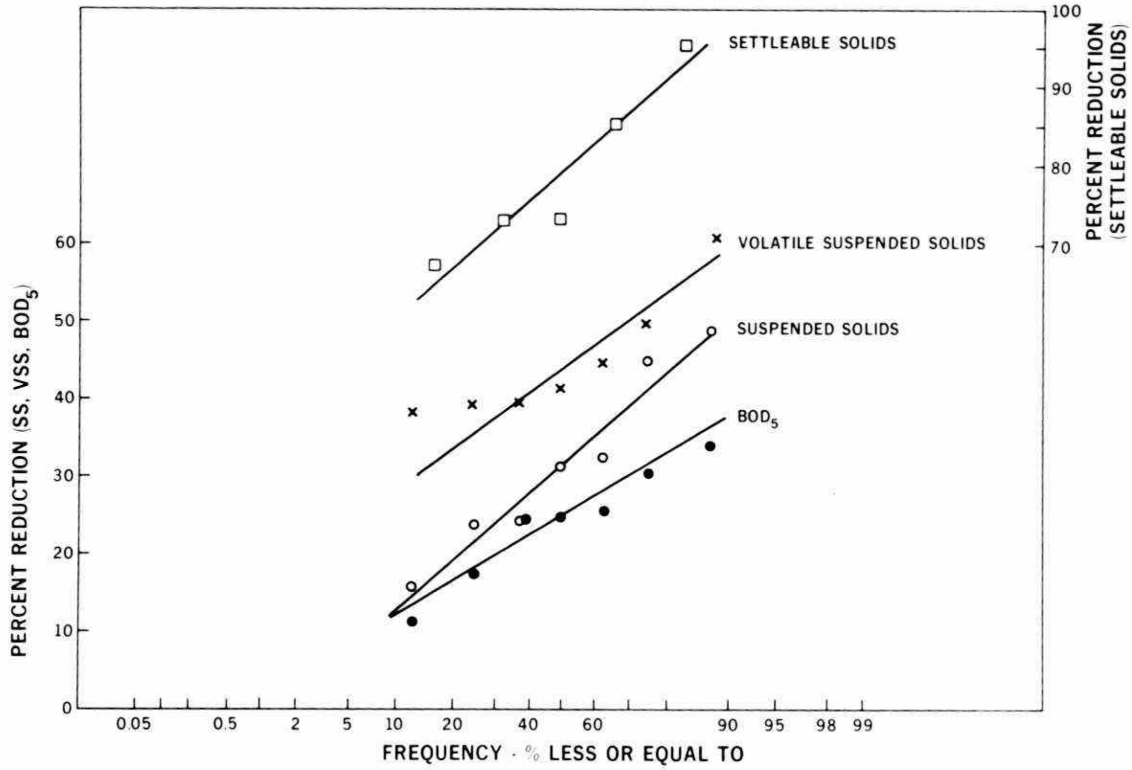


FIGURE 19. PERCENT REDUCTION ACROSS CWC FOR STORM EVENTS WITH A FIRST FLUSH

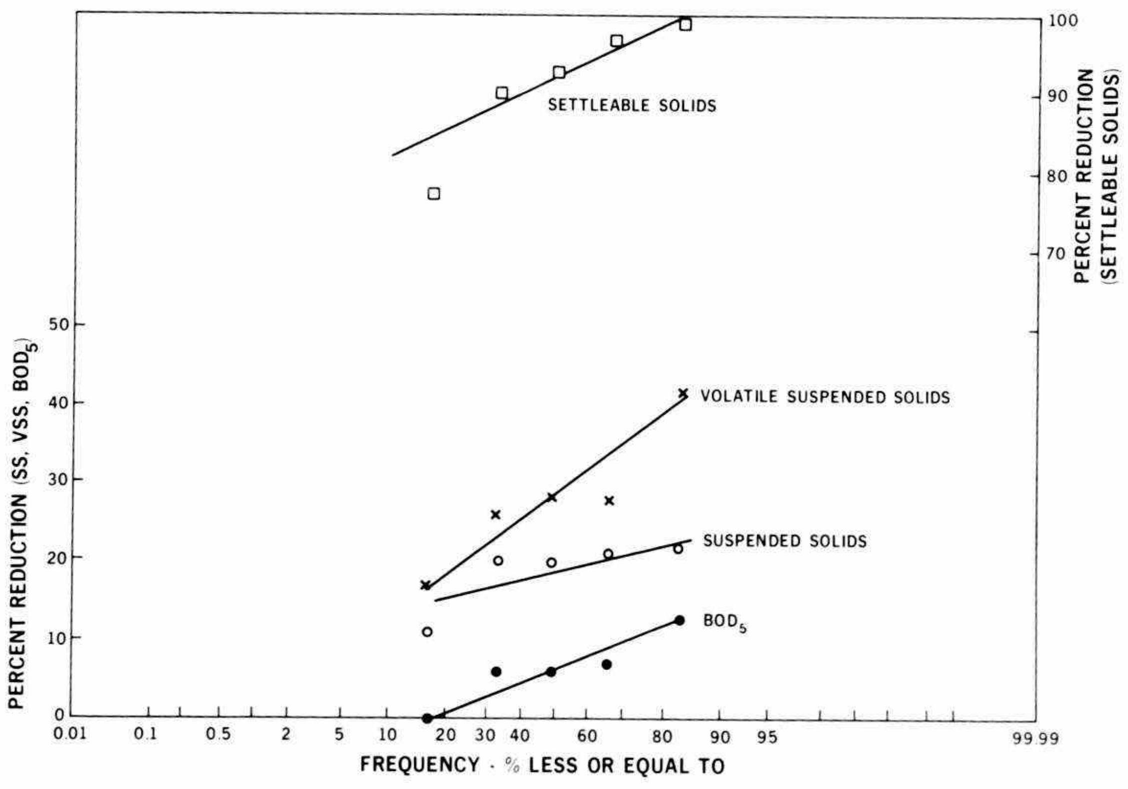


FIGURE 20. PERCENT REDUCTION ACROSS CWC FOR STORM EVENTS WITHOUT A FIRST FLUSH

Overall mass removal for both types of storm events are presented in Figure 21. The percentage mass removal or partitioning into the concentrate varied within a relatively narrow range, about 50 percent for storms with a first flush. Percentage mass removals during storms without a first flush were lower and more variable (Appendix B, Table B-9). It is readily apparent that, for the three parameters monitored, the major fraction of pollutant removal was due to hydraulic flow splitting. Average percentage mass pollutant separations by enrichment were 20%, 29%, and 16% for SS, VSS, and BOD_5, respectively, under first flush conditions, while separation due to hydraulic flow splitting was 32 percent for each parameter. In storm events without a first flush, the higher centrate fraction obtained reduced the mass separation due to hydraulic split to 25 percent. However, the enrichment mass fraction was also reduced to 13%, 18%, and 1.3% for SS, VSS, and BOD_5, respectively.

6.2.2.3 Centrate and concentrate characteristics. Relationships between SS concentrations in the influent and centrate are illustrated in Figures 22 and 23. In these figures, the equivalence line corresponds to 'no concentration change'. The data points are raw sewage and centrate concentrations in individual pairs of samples during various storm events. The solid line is a least squares fit to the data forced through the origin. It can be seen that the centrate SS concentration increases as the raw sewage SS concentration increases in both first flush and non-first flush storms, even though the hydraulic loading to the screen was maintained essentially constant through each storm. The concentration effect remained small as influent suspended solids loadings increased. The average reductions shown are those given in Table 5.

Although the centrate is the treated stream discharged by the screen, the pollutant concentrations in the centrate are relatively high, especially in storms with a first flush (Table 6). The characteristics of CWC concentrate are also presented in Table 6. Comparisons of raw sewage and centrate concentration values show that the overall effect of treatment is not great. Preliminary investigations of additional treatment of the concentrate by screening and settling were also carried out. The screening tests are discussed in Sections 6.3.2 and 7.3.2.2.

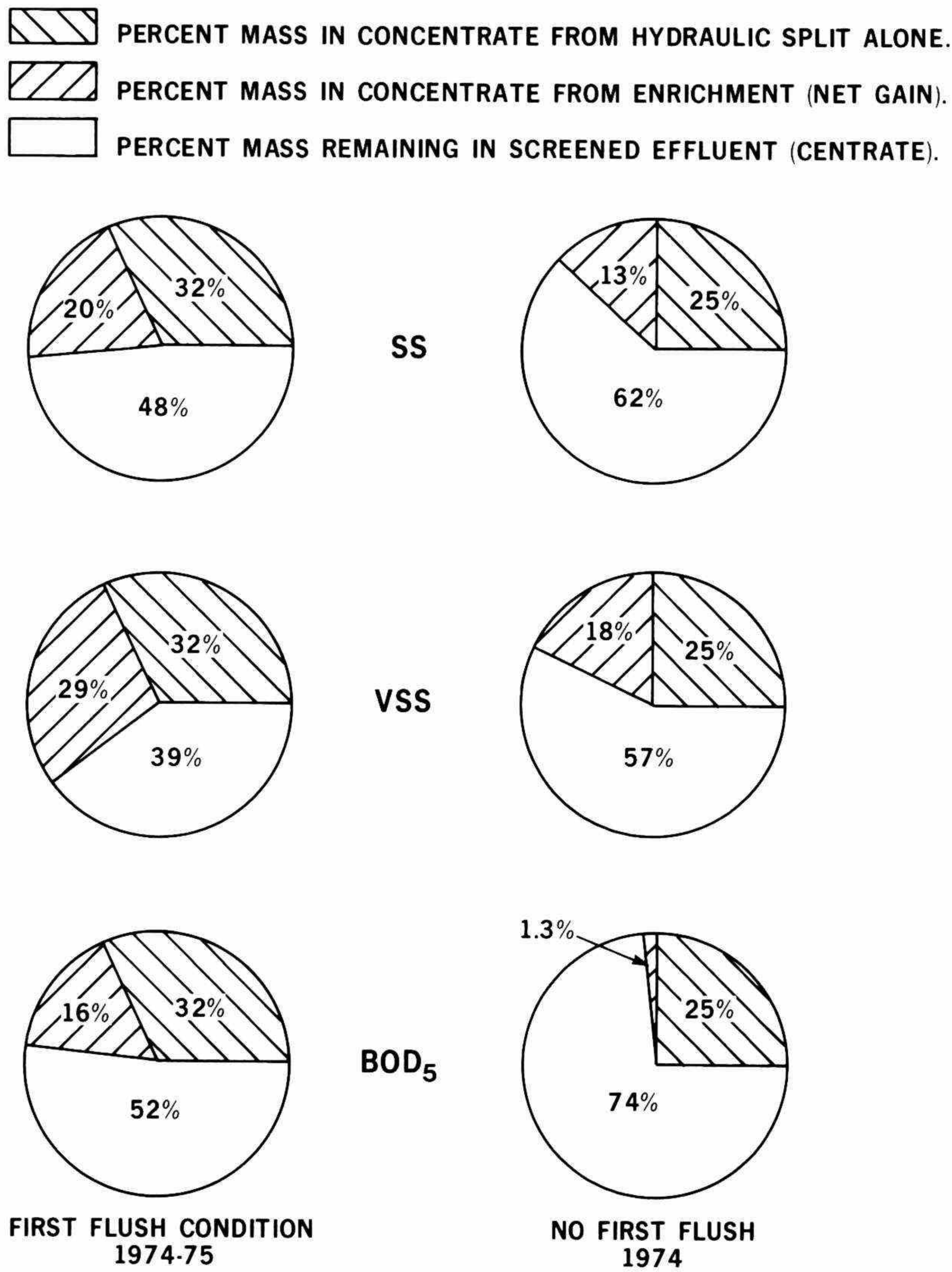


FIGURE 21. POLLUTANT MASS DISTRIBUTION IN CENTRATE AND CONCENTRATE RESULTING FROM SCREENING BY THE CWC IN WET WEATHER OPERATION

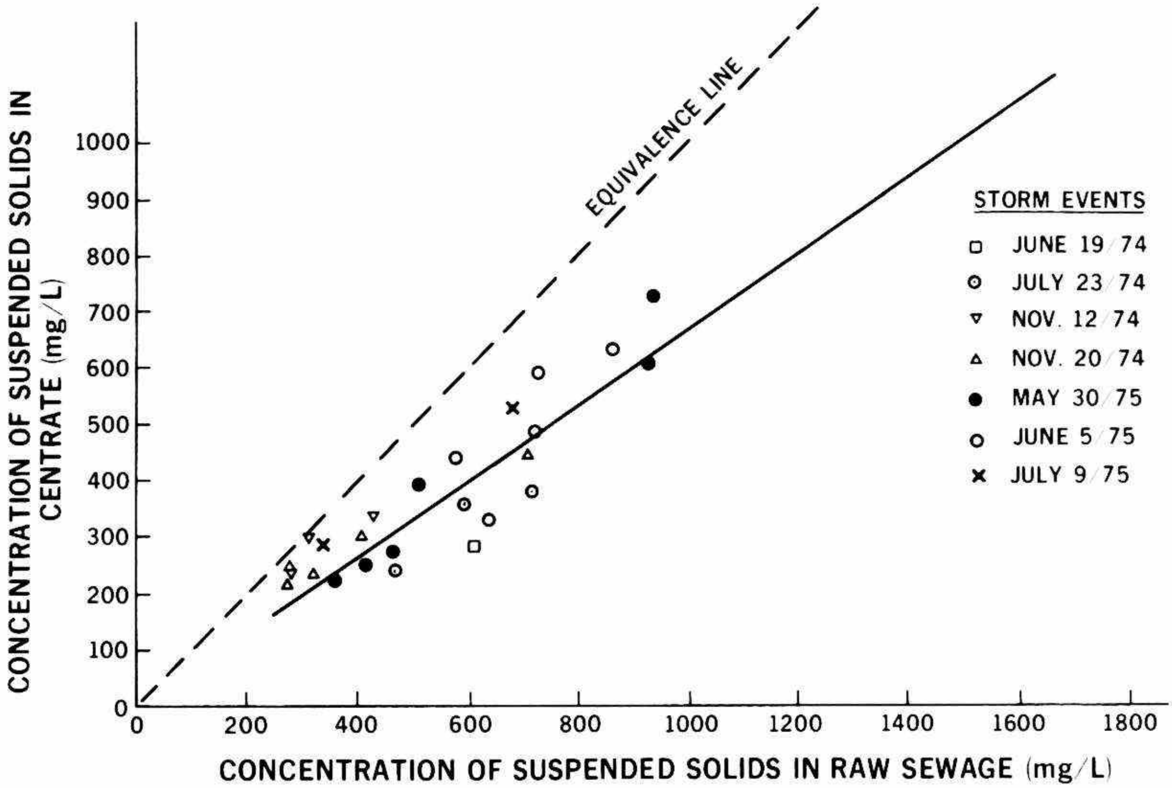


FIGURE 22. CONCENTRATIONS OF SUSPENDED SOLIDS IN RAW SEWAGE VS CONCENTRATIONS OF SUSPENDED SOLIDS IN CWC CENTRATE - FIRST FLUSH CONDITIONS

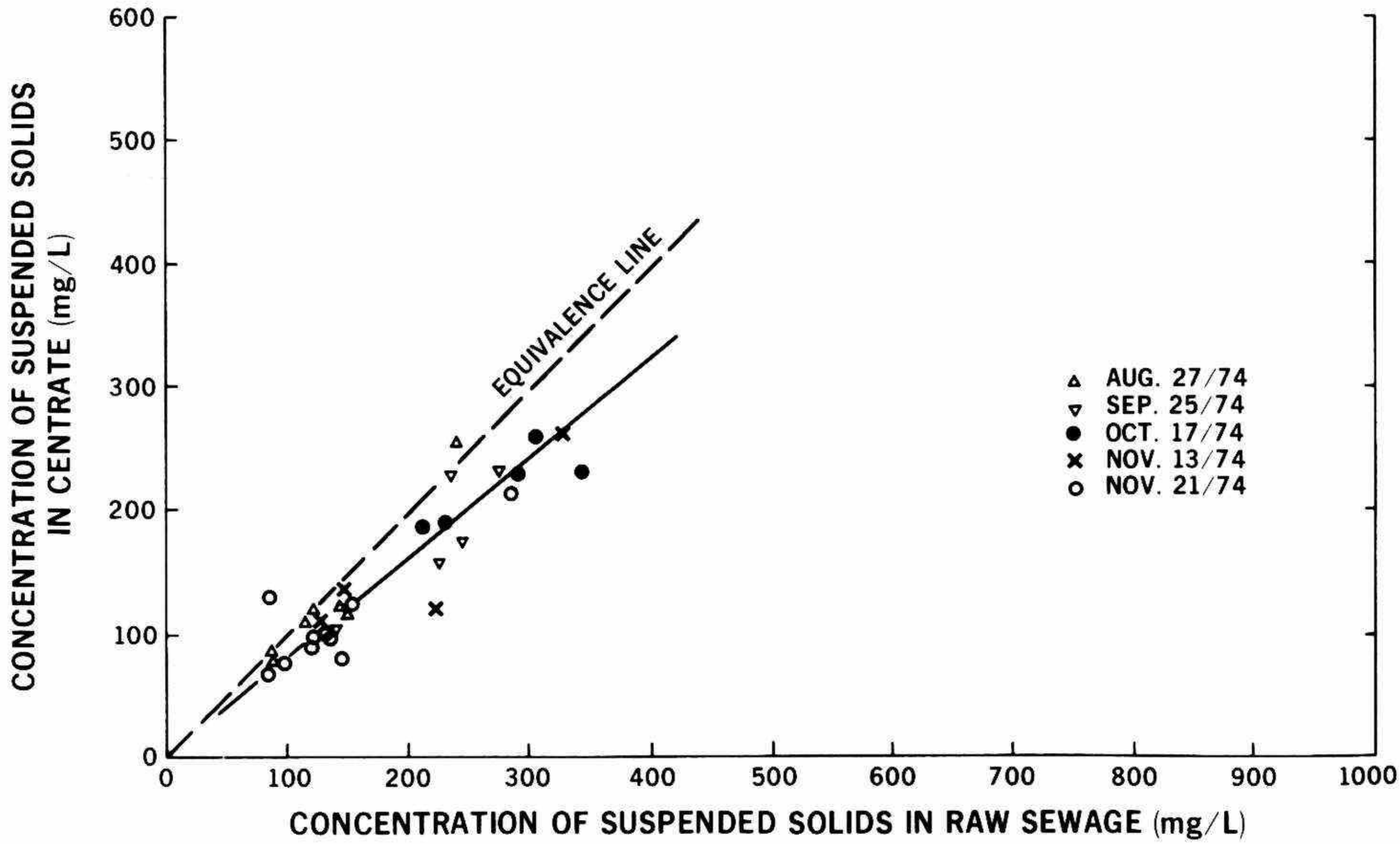


FIGURE 23. CONCENTRATIONS OF SUSPENDED SOLIDS IN RAW SEWAGE VS CONCENTRATIONS OF SUSPENDED SOLIDS IN CWC CENTRATE - NON-FIRST FLUSH CONDITIONS

TABLE 6. CWC CENTRATE AND CONCENTRATE CHARACTERISTICS - WET WEATHER OPERATION

		SS (mg/L)	VSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	Total P (mg/L)	Settleable Solids (mL/L)
Centrate								
First Flush	Average	360	116	93	364	19	4.6	2.3
	Minimum	265	75	60	204	13	3.5	0.4
	Maximum	454	167	140	480	28	6.0	4.8
Non-First Flush	Average	154	65	65	190	18	3.6	0.7
	Minimum	106	46	33	181	12	2.4	0.1
	Maximum	203	108	114	198	28	5.5	3.0
Concentrate								
First Flush	Average	587	247	148	592	22	5.6	11.4
	Minimum	400	113	87	270	15	4.2	6.5
	Maximum	729	375	277	1043	32	7.8	19.5
Non-First Flush	Average	245	131	73	229	19	3.9	9.1
	Minimum	177	88	44	226	14	2.9	5.3
	Maximum	356	197	135	231	29	5.6	16.0

Note: Minima and maxima are averages for an event.

Static settling tests were performed on raw sewage and concentrate using columns 150 mm (six inches) in diameter and 1.5 m (five feet) high, with sampling ports at 0.3-m (one-foot) intervals. The results in Table 7 show that concentrate settled at least as well as raw sewage, and it was concluded that no problems would be anticipated in treating concentrate in primary clarifiers.

TABLE 7. SETTLING TESTS ON RAW SEWAGE AND CWC CONCENTRATE - WET WEATHER November 20, 1974 - 2:30 p.m.

Distance from Surface (m)	Concentration of Settleable Solids after Settling					
	0 h	1 h	2 h	0 h	1 h	2 h
	Raw Sewage (mg/L)			CWC Concentrate (mg/L)		
0.3	500	250	210	675	200	175
0.6	500	250	260	675	260	185
0.9	500	260	215	675	260	185
1.2	500	250	214	675	260	225
% Reduction at 0.3 m		50%			70%	

6.2.3 Operational considerations

An indication of screen panel damage during the study is given in Figure 24. The data do not permit an appraisal of ultimate screen life, but it is obvious that the frequency of screen panel failure increased with accumulated operating time. The two sets of screen panels under study had accumulated operating times of 348 and 439 hours, with 20 and 18 screen failures, respectively. The improved performance of the second set could be due to improved screen panel construction or the improved backwash system. It is reasonable to assume that less stress is exerted on clean screen panels, which have a larger open area. Puncture type failures could occur at any time and do not reflect a weakness in panel construction. Of the damaged panels, 13 in the first set and 10 in the second set could be repaired with silicone sealer. Panels could usually be repaired if the damage was confined to tears along the outer panel frame.

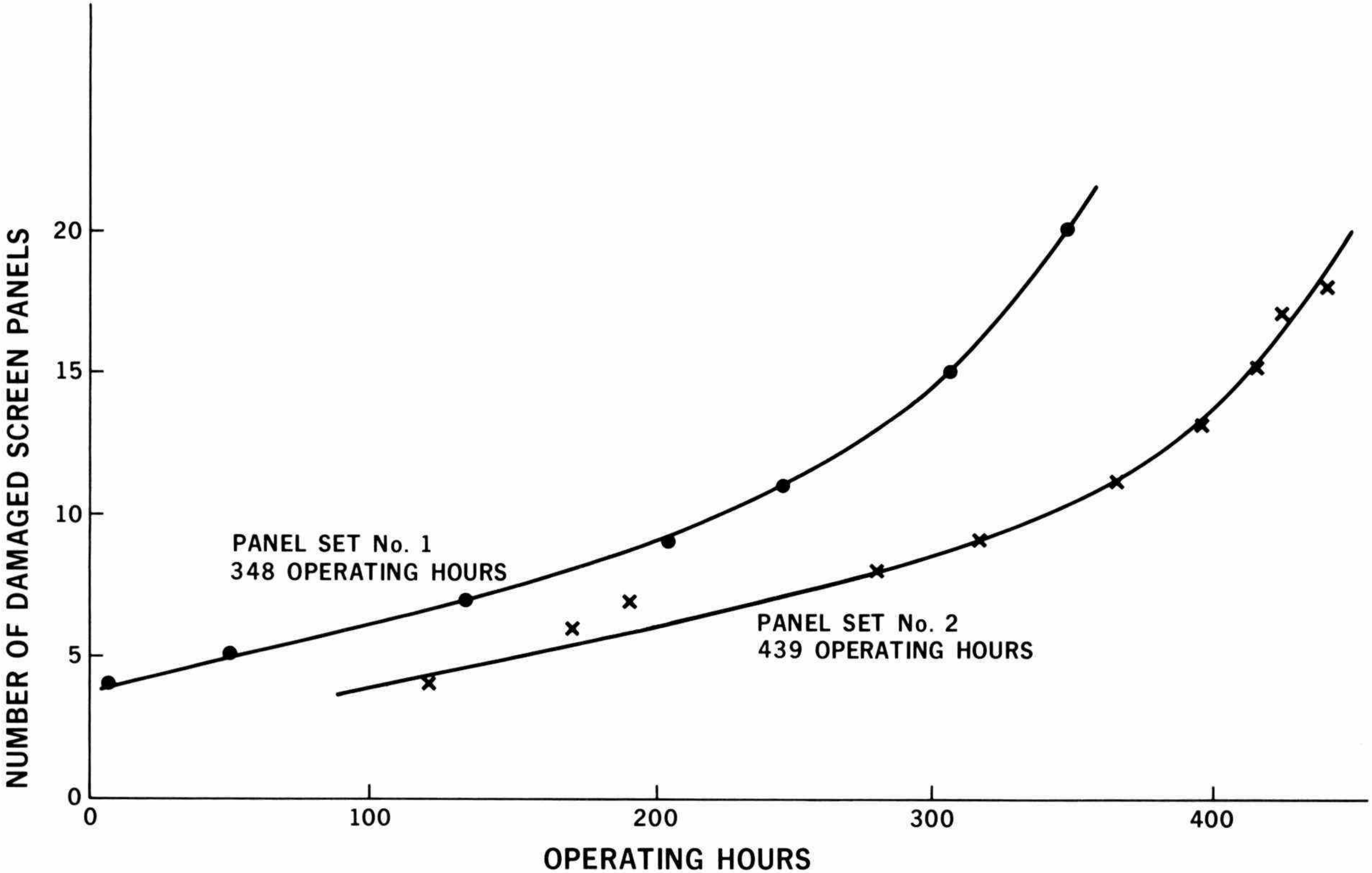


FIGURE 24. RELATIONSHIP BETWEEN CWC SCREEN DAMAGE AND HOURS OF OPERATION

Some form of pre-screening may be required to protect the CWC screen panels. This was demonstrated during the final effluent polishing phase of the study (discussed in Section 7.5) in which not a single screen panel was damaged during 129 hours of operation.

The basic CWC unit, which includes the screen cage with electrical control devices, is well designed for trouble free operation. The screen cleaning system is the weak part of the unit. As received, the backwash system failed completely during first flush conditions making the device essentially useless for storm water treatment. Although the backwash system performed fairly well after major modifications were made there is still room for improvement.

For a five-minute screening cycle with a 30-second backwash, consumption of materials for screen cleaning was as follows: ZEP screen-degreaser, 120 mL hot water, 14 L (3.1 gal) continuous cold water backwash, 0.9 L/s (11.5 gpm) and propane gas, approximately 0.7 kg (1.5 lb) per operating hour.

6.2.4 Flotation cell performance

The CWC-associated flotation cell was designed to utilize the dissolved air which became entrained in the centrate during the screening process. Comparison of flotation cell effluent with centrate indicated no statistically significant improvement in pollutant reduction.

6.3 DSM Screen

6.3.1 Hydraulic capacity and operational experience

The three screen plates evaluated with the DSM screen had apertures of 88, 150, and 305 micrometres. Preliminary evaluation led to the rejection of the 88 and 150-micrometre screens. The 305-micrometre screen had a hydraulic capacity of 0.78 $m^3/m^2 \cdot min$ (16 gpm/ft^2), was the least prone to blinding, and gave pollutant removals equivalent to those obtained with the 150-micrometre screen.

The screen accepts (sludge fraction) had a suspended solids concentration of three to six percent. Concentrations were generally lowest during first flush conditions, especially when partial screen flooding occurred.

Four first-flush storm events were monitored when the mechanical brush was being used for cleaning. The hydraulic loadings applied during each event and the data on total precipitation and storm duration are given in Table 8. During the storm of July 9th, the DSM screen was used for "second-stage" screening of CWC concentrate. The small gasoline driven pump used to feed the screen during this storm limited the loading rate to 0.49 $m^3/m^2 \cdot min$ (10 gpm/ft^2). The maximum hydraulic capacity of the screen in this application could not be determined as there was no sign of flooding at the applied loading rate.

During severe first flush conditions, the flow rate to the unit was reduced temporarily by partial plugging in the intake line of the pump feeding the screen. Temporary screen flooding also occurred under first flush operation. At other times it was noted that considerable quantities of free water ran from each side of the screen plate whenever solids were piled up by the motion of the reciprocating brush; this often happened when suspended solids loadings were heavy and when permanent screen blinding had occurred. No other operating problems were noted.

6.3.2 Pollutant removal efficiency

The average reduction of pollutants for each storm event monitored, and an overall mean calculated for the storms other than that of July 9th are given in Table 8. The quality of screened effluent and overall mean values, excluding the storm of July 9th, are shown in Table 9. Results for the July 9th storm are discussed separately at the end of this section. The percentage removals obtained during the August 25th storm were considerably lower than those for the storms of May 30th and June 5th. Although screened effluent quality was relatively constant for all three storms, concentrations of most parameters were greater than were measured in dry-weather sewage.

Intensive sampling of raw sewage and screened effluent from the DSM screen and Rotostrainer was carried out during the storm event of August 25th. The suspended solids concentrations of these samples are plotted in Figure 25, below the corresponding profile of raw sewage flow to the WPCP. The reduction in the concentration of suspended solids was minimal during this storm. The figure shows that peak values of influent suspended solids were obtained in advance of the peak hydraulic flow to

TABLE 8. PERFORMANCE OF DSM SCREEN DURING STORM EVENTS

	Storm Event*		Hydraulic	Pollutant Removals (%)							
Date (1975)	Duration (h)	Precipitation (mm)	Loading ($m^3/m^2 \cdot min$)	SS	VSS	BOD_5	COD	TKN	Total P	Settleable Solids	Number of Samples
May 30	1.75	17	0.8	22.7	40.9	12.9	21.4	16.2	8.0	61.0	8
June 5	3	21	0.8	19.7	31.0	11.3	14.9	15.7	14.1	64.0	7
July 9**	1	4	0.5	27.0	44.0	39.0	13.3	2.3	2.0	65.5	3
August 25	4	34	0.8	7.4	20.2	8.1	11.5	2.4	6.2	41.9	17
Average	--	--	--	19.2	34.0	17.8	15.2	9.2	7.6	58.1	--

* All events had first flush conditions.

**Screen was being fed CWC-concentrate, and values were not included in calculations of averages.

Screen aperture: 305 micrometres.

TABLE 9. DSM SCREEN EFFLUENT CHARACTERISTICS DURING STORM EVENTS*

Date	SS (mg/L)	VSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	TOTAL P (mg/L)	Settleable Solids (mL/L)
1975							
May 30	563	155	89	539	19	4.1	5.7
June 5	524	154	96	430	17	4.4	3.4
July 9**	529	205	117	547	31	7.2	6.9
August 25	544	160	74	366	20	4.6	3.1
Average	540	169	94	471	22	5.1	4.7

* All events had first flush conditions.
**Feed to screen was CWC-concentrate: these values were not used in calculations of averages.
Screen plate: 305-micrometre aperture.

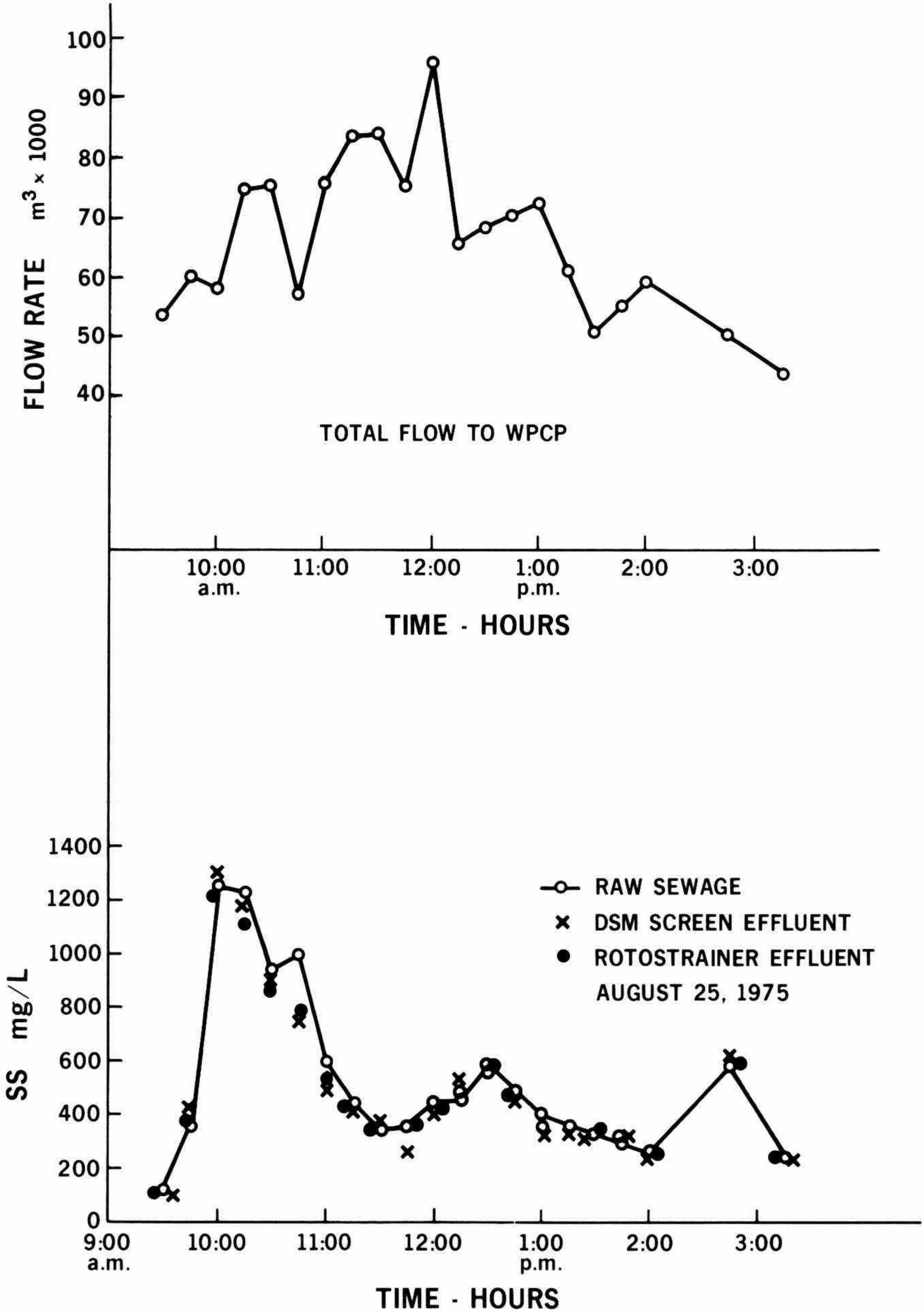


FIGURE 25. SUSPENDED SOLIDS CONCENTRATION PROFILE ACROSS DSM SCREEN AND ROTOSTRAINER - FIRST FLUSH CONDITIONS

the WPCP. Much lower values of influent suspended solids were obtained when the peak hydraulic flow was reached. Complete concentration profiles for all storm events are included in Appendix B.

During the storm of July 9th, when CWC-concentrate was fed to the DSM screen, the influent concentrations of various parameters were considerably higher than during the other storm events. Percentage reductions of SS, VSS, and BOD_5 (Table 8) were also higher, as were the concentrations in the screened effluent of all parameters other than suspended solids (Table 9). Although the results indicated the basic feasibility of a second-stage static screen for treating CWC-concentrate, a higher recovery of settleable and suspended matter would be desirable. Further work is needed to determine the best screen aperture to achieve this goal.

6.4 Hydrasieve

6.4.1 Hydraulic capacity

Screen plates with 254, 762, and 1524-micrometre apertures were supplied with the Bauer Hydrasieve. The 254-micrometre screen blinded very rapidly, and its hydraulic capacity of 0.22 $m^3/m^2 \cdot min$ (4.4 gpm/ft^2) was to low to be of practical value. The other two screens could each handle 0.43 $m^3/m^2 \cdot min$ (19 gpm/ft^2), a value limited by the influent and effluent nozzle configurations. Since the 762-micrometre screen could handle this capacity when clean and gave some pollutant removals, it was selected for wet weather test work.

Five of the seven storm events during which the performance of the screen was monitored had first flush conditions. The hydraulic loadings during each event and the duration and total precipitation of each storm are listed in Table 10.

During initial testing in 1974, the 762-micrometre screen was found to be partially blinded during the early part of storms with a first flush. In an attempt to reduce blinding, the Hydrasieve was modified to enable feed to be applied in a "waterfall" fashion. This reduced the hydraulic capacity to 0.42 $m^3/m^2 \cdot min$ (8.5 gpm/ft^2). Since screen blinding remained a problem, the waterfall method of feeding was abandoned.

TABLE 10. PERFORMANCE OF HYDRASIEVE DURING STORM EVENTS

Storm Event			Hydraulic	Pollutant Removals (%)							
Date (1975)	Duration (h)	Precipitation (mm)	Loading ($m^3/m^2 \cdot min$)	SS	VSS	BOD_5	COD	TKN	Total P	Settleable Solids	Number of Samples
November 24/74*	5.0	18	0.4**	3.4	37.8	0	9.0	1.0	5.5	2.7	5
November 13	3.0	8	0.4**	11.0	33.0	6.0	1.0	3.0	16.0	6.7	4
November 20*	2.0	25	0.4**	4.8	8.0	12.6	3.0	9.0	12.0	20.3	5
November 21	8.0	9	0.4**	6.2	4.1	3.0	1.6	8.0	0	2.8	9
December 2*	2.0	5	0.9	3.3	12.0	0	5.0	4.0	4.3	10.0	3
May 30/75*	1.8	17	0.9	20.5	31.0	10.4	24.4	12.9	1.8	48.0	8
June 5*	2.5	21	0.9	15.2	18.8	3.2	6.8	10.5	8.7	32.0	6
Average (First flush)			--	9.4	21.5	5.2	9.6	7.5	6.5	22.6	--
Average (Non-first flush)			--	8.6	18.5	4.5	1.3	5.5	8.0	4.8	--

* Storm with a first flush.
**Feed applied as a waterfall

6.4.2 Pollutant removal efficiency

The pollutant removal efficiencies achieved by the Hydrasieve under storm conditions are shown in Table 10. Results are presented as the arithmetic mean of removals for various parameters during each storm event. The overall average removals of all the parameters except COD and settleable solids were similar for storms with and without a first flush, but the average removal values for individual storms within the two groups varied widely. For example, average removal of suspended solids in storms with a first flush varied from 3.3 percent to 20.5 percent. Average characteristics of effluent from the screen for each storm are summarized in Table 11. The data illustrate the roughing nature of the treatment obtained.

The sludge fraction from the screen had a solids concentration of about two percent during periods when the screen was operating without flooding. The solids level was depressed to this low value by the water which dripped constantly off the screen plate. When the screen partially flooded, the solids concentration was lower.

6.5 Rotostrainer

6.5.1 Hydraulic capacity

This screen was operated during one storm event only (Figure 25). Hydraulic loading during the storm, which had a first flush, was maintained at 0.66 $m^3/m^2 \cdot min$ (13.5 gpm/ft^2) based on the total cylinder area. No blinding or other problems were noted. In the absence of further storm events the maximum wet weather hydraulic capacity of the Rotostrainer could not be established.

6.5.2 Pollutant removal efficiency

Table 12 shows percentage removals and effluent concentrations for various parameters. Removals were minimal, as expected, since the Rotostrainer is primarily a roughing device. During the storm the sludge from the unit had a solids concentration of about six percent.

6.6 Summary of Screen Performances

The four devices were compared on the basis of hydraulics, pollutant removal, and general equipment reliability. Major differences in screen design or operation, including intended service by the manufacturer, required that comparisons be based on the equipment as

TABLE 11. HYDROSIEVE EFFLUENT CHARACTERISTICS DURING STORM EVENTS

Date	SS (mg/L)	VSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	Total P (mg/L)	Settleable Solids (mL/L)
1974							
November 12*	328	80	133	358	21	5.2	3.8
November 13	185	71	131	243	16	3.7	2.2
November 20*	375	129	74	282	14	3.5	2.8
November 21	126	63	67	218	12	2.7	1.4
December 2*	328	136	123	367	24	5.3	3.4
1975							
May 30*	571	174	89	449	20	4.3	7.0
June 5*	546	171	103	528	18	4.5	5.3
Average*	430	138	104	397	19	4.6	4.5
Average	156	67	99	231	14	3.2	1.8

Screen plate: 762-micrometre aperture.

* Storm with first flush.

TABLE 12. PERFORMANCE OF ROTOSTRAINER DURING A STORM EVENT ON AUGUST 25, 1975

	SS	VSS	BOD_5	COD	TKN	Total P	Settleable Solids
Percent Reduction	4.5	11.9	10.2	7.5	2.5	7.2	23.3
Effluent Concentration (mg/L)	545	173	69	389	19	4.3	4.1 (mL/L)

Screen aperature size: 500 micrometre
Feed rate: 0.73 $m^3/m^2 \cdot min$, (13.5 gpm/ft^2), based on total screen area.
Sets of samples: 17
Duration of storm: four hours
Precipitation: 34 mm (1.35 inches)
First flush condition

supplied. Some of the major equipment differences were: continuous vs batch operation, the production of a concentrate vs a sludge, and self-cleaning vs automated in-line or manual cleaning.

The hydraulic capacity of each device was compared on the basis of unit area while operating with the most suitable screen aperture. The screen apertures selected for the comparisons of the devices were the minimum practical openings for the Belleville application. The use of screens with the next finer aperture size available resulted in poor operation and did not necessarily improve pollutant removals. Hydraulic capacity varied widely and, in addition to effects due to the screen plate apertures, was largely affected by the mode of feed application. For example, pressurized feed application with the CWC produced up to three times the hydraulic capacity achieved with gravitational flow to the DSM screen. Dilution of the concentrate or sludge was common with all units studied and occurred as a result of temporary screen blinding and associated flooding during the initial stages of a severe storm event.

Figures 26, 27, and 28 provide comparisons of screen performance on the basis of hydraulic capacity and pollutant removal efficiency for common storm events. Because of the limited number of common storm events, no statistical analysis of the data was performed.

The relative effectiveness of the CWC, DSM screen and Hydrasieve in pollutant removal, assessed on a concentration or enrichment basis, is illustrated in Figures 26 and 27. Settleable matter was most readily removed, followed in decreasing order by VSS, SS, COD, BOD_5, TKN, and total P. The settleable matter includes fractions of the other parameters. In Figure 28, a similar comparison between the Rotostrainer and DSM screen is shown. These data are from one storm event.

In the case of the CWC the proportion of mass transferred to the concentrate by the hydraulic flow split must be considered in relation to the actual enrichment effect of the device. It has been observed that the mass transferred by flow splitting can be significantly larger than the actual net enrichment. Therefore, in Figure 26, pollutant removals for the CWC are also reported on a mass basis; the overall mass removed is subdivided into portions due to enrichment and due to hydraulic flow splitting. Pollutant removals for the other three screens are based on

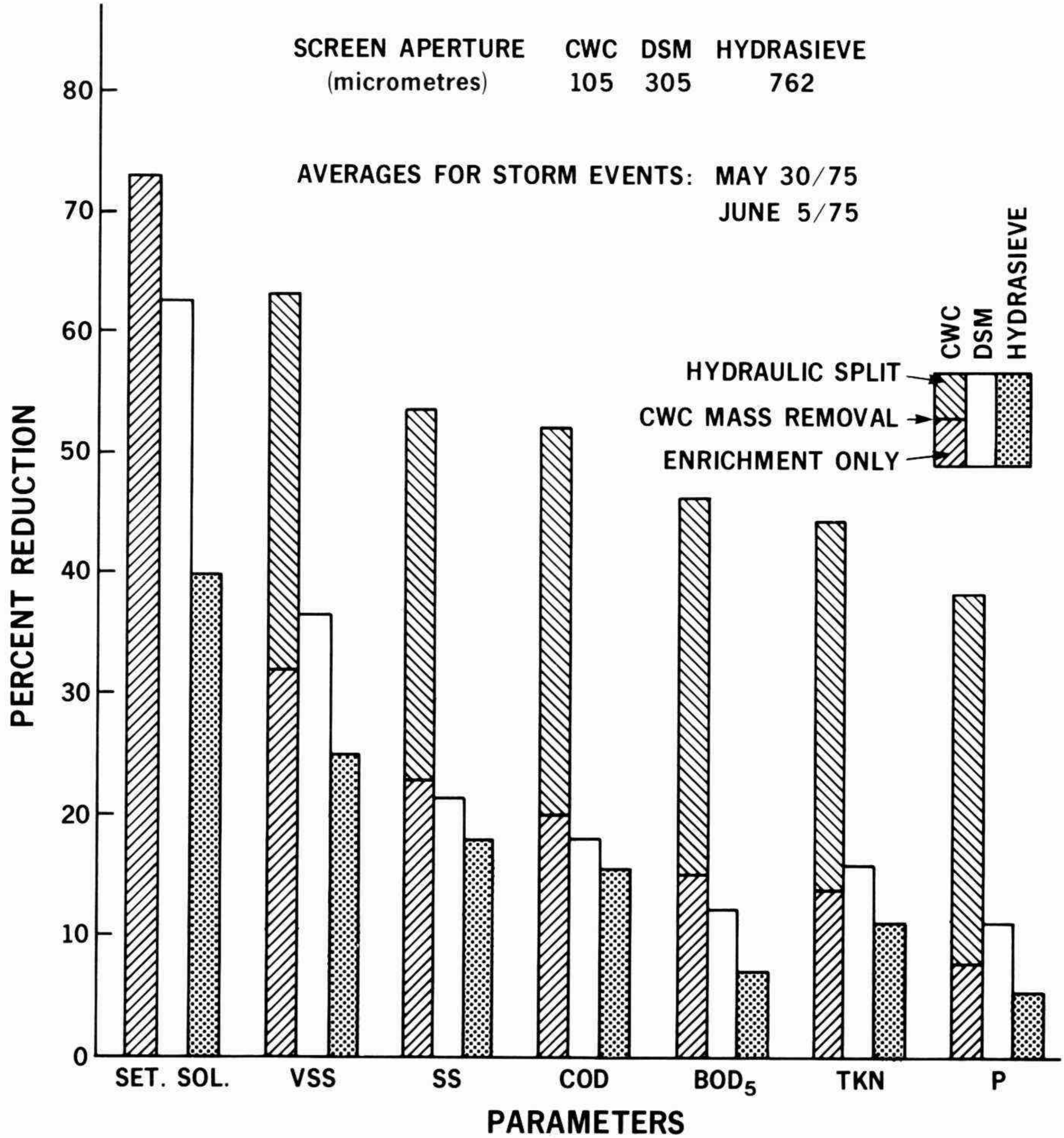


FIGURE 26. SCREEN PERFORMANCES OF CWC, DSM, AND HYDRASIEVE - FIRST FLUSH CONDITIONS

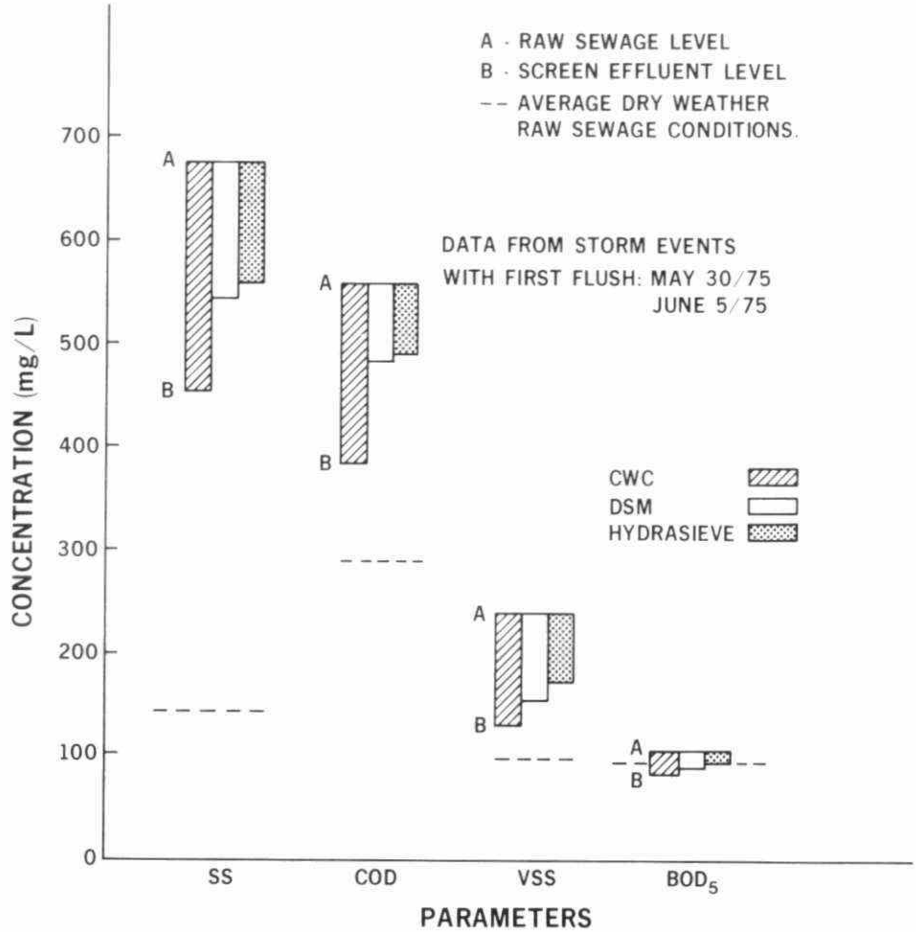


FIGURE 27. COMPARISONS OF POLLUTANT LEVELS IN SCREEN EFFLUENTS FROM CWC, DSM, AND HYDRASIEVE

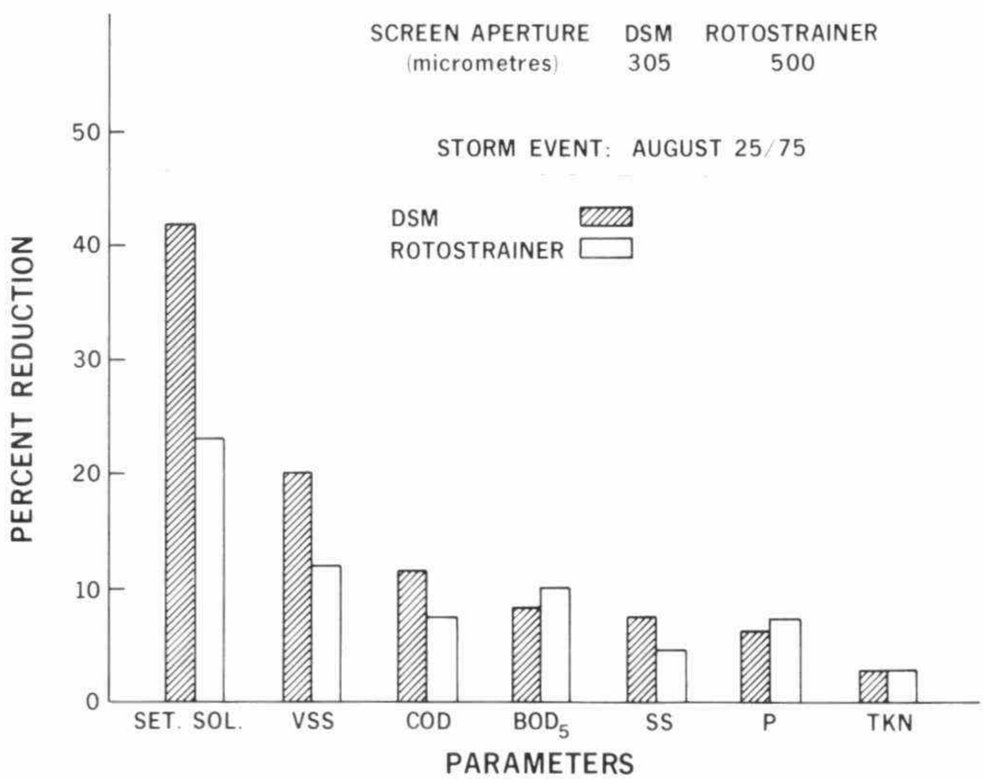


FIGURE 28. SCREEN PERFORMANCES OF DSM AND ROTOSTRAINER - FIRST FLUSH CONDITIONS

concentration changes. In the absence of screen flooding, these values are identical to mass removals for all practical purposes. Because comparisons of settleable solids removals in Figures 26 and 28 are based on changes in solids volume (as determined from the Imhoff cone test), differentiation due to enrichment and flow splitting (CWC) is not felt to be justified.

The quality of effluents from three of the screens, used to treat a common raw sewage, is shown in Figure 27. A comparison of Figures 26 and 27 shows that a high percentage pollutant removal does not necessarily produce an acceptable effluent quality.

On the basis of the Belleville study, it was concluded that the CWC and DSM screen have a potential for moderate pollutant removals whereas the Hydrasieve and Rotostrainer are suitable only for roughing treatment. The performance of the Hydrasieve might equal that of the DSM screen if automated screen cleaning was used. The advantages and disadvantages of each unit are summarized in Table 13. Capital and operating costs for the CWC, DSM screen, and Rotostrainer are given in Appendix C.

TABLE 13. ADVANTAGES AND DISADVANTAGES OF THE SCREENING DEVICES EVALUATED

Device	Advantages	Disadvantages
CWC (Screen aperture: 105-micrometres)	Good hydraulic capacity; good pollutant removal.	Screen panels easily damaged; backwash system inadequate as supplied; occasional manual screen cleaning; batch operation; no disposal sludge produced; requires storage capacity or additional units; requires frost-free environment; requires coarse pre-screening; regular inspection for screen damage; high operating costs.
DMS Screen (Screen aperture: 305-micrometres)	Good hydraulic capacity; fair pollutant removal; reliable screen cleaning; sludge produced for disposal; continuous operation; indestructible screen plate; low operating cost.	Tendency toward screen flooding; may require frost-free environment.
Hydrasieve (Screen aperture: 762-micrometres)	Good hydraulic capacity; no moving parts; sludge produced for disposal; good roughing screen; continuous operation; indestructible action plate; no heated building required; low operating cost.	No screen cleaning device; tendency to screen flooding; only practical with larger screen aperture; suitable for roughing only.
Rotostrainer (Screen aperture: 500-micrometres)	Good hydraulic capacity; self cleaning; good roughing device; sludge produced for disposal; no screen flooding; continuous operation; long wearing screen cylinder; low operating costs.	Fibre stapling with screens having apertures of less than 500 micrometres; maintenance of wiper blade and drum seals; requires frost-free environment.

7 RESULTS - DRY WEATHER OPERATION

7.1 General Discussion

An extensive evaluation of the performance of the screening equipment on dry-weather degritted raw sewage was carried out. The first phase of the dry weather operation in 1974 was a debugging period. Dry weather operation was essential for testing modifications or improvements made to the equipment, particularly the CWC backwash system. The units then could be made ready for more severe service conditions during storm events. The accumulation of operating time in dry weather also permitted assessment of the reliability of each screening device under extended usage. Some equipment limitations or weaknesses, such as screen blinding, which would not likely have been observed during the infrequent and brief storm events were revealed. Similar effects had been reported in previous studies [5, 10].

In 1975 operating period of the CWC was essentially trouble-free, and more or less regular daily operation at constant flow and cycle time was possible. The DSM screen and Rotostrainer were not installed until 1975 but they were considerably simpler to operate and maintain and needed no major modifications.

Dry weather operation was used to provide information on the potential use of the screens as a replacement or supplement for conventional primary treatment. The Belleville site was not an ideal location for primary treatment studies, however, because the dry weather raw sewage was always highly diluted due to infiltration. Other limitations which restricted screen-clarifier comparison were sludge wasting, digester overflow, and the suction intake locations to the screening units, and were discussed previously. Primary clarifier operating performance, based on WPCP records, has been summarized in this chapter to provide some basis for comparison of screen performance.

7.2 Degritted Raw Sewage Characteristics

Unlike combined sewage, which displayed wide variations in both quality and quantity during a storm event, dry weather sewage quality and flow were comparatively stable. The occasional high values encountered may have been due to industrial spills, dumps, or sewer flushing.

Because of the generally small variations in the quality of raw sewage, individual grab samples were averaged without weighting for flow. Overall means and standard deviations for concentrations of key parameters such as SS, VSS, BOD_5, TKN, total P, and settleable solids in raw sewage during the 1974 and 1975 seasons are presented in Table 14. Nutrient analyses were not carried out on dry weather sewage during the 1975 operating season. Concentrations of all parameters measured during 1975 were somewhat higher than during 1974. The yearly means for suspended solids and BOD_5, as reported in the Ontario Ministry of the Environment Operating Summaries [11], have also been included. Although these values were not expected to agree with study results due to the different method and timing of sample collection, agreement was excellent for 1974.

7.3 Equipment Performance

7.3.1 Centrifugal wastewater concentrator

7.3.1.1 Hydraulic capacity. Nominal and actual hydraulic capacities, hydraulic splits, and cycle times are shown in Table 15. The decrease in hydraulic capacities during 1974 was caused by the inadequate backwash system. Although the hydraulic split was acceptable during the 1974 period the corresponding screen cycle time was very erratic when controlled automatically according to concentrate flow or a preset hydraulic split. The long cycle times during 1974 reflect extended operation at low hydraulic splits. Short cycles of one minute were common during the early start-up period because of such factors as waste sludge in the raw sewage or dirty screen panels. Consequently, cycle time was set arbitrarily at either five to ten minutes, depending on the raw sewage quality and on the condition of the screen panels. In general, a ten-minute cycle time was used until noon each day, and then the cycle was reduced to five minutes in order to maintain an acceptable split.

The "actual" flow rates, shown in Table 15, are based on a typical five-minute cycle. During June and July of 1975 the unit was operated for short periods at maximum nominal flow rates of about 12 274 m^3/d (2.7 mgd). At greater flow rates, the hydraulic split began to deteriorate quickly. The effect of nominal flow rate on the hydraulic

TABLE 14. SUMMARY OF DRY WEATHER RAW SEWAGE CHARACTERISTICS

Year		Parameter						
		SS (mg/L)	VSS (mg/L)	BOD_5 (mg/L)	TKN (mg/L)	Total P (mg/L)	Settleable Solids (mL/L)	Number of Samples
1974	Mean	140	88	87	19.8	4.6	4.0	335
	WPCP Mean*	141	--	85	--	--	--	38
	Range**	55-405	20-300	15-260	11-43	2.7-12.0	0.1-20.0	--
	Standard Deviation	54	34	30	5.0	1.1	2.0	--
1975	Mean	152	110	101	--	--	7.0	348
	WPCP Mean	88	--	84	--	--	--	40
	Range**	20-456	16-264	12-240	--	--	0.2-13.0	--
	Standard Deviation	40	25	24	--	--	1.8	--

* Data from Ontario Ministry of the Environment Operating Summaries [11].
**Based on hourly grab samples.

TABLE 15. HYDRAULIC FLOWS, HYDRAULIC SPLITS, AND CYCLE TIMES FOR CWC DURING DRY WEATHER OPERATION

	Monthly Averages					
	Hydraulic Flow m^3/d (mgd)		Actual Capacity $m^3/m^2 \cdot min$ (gpm/ft^2)	Hydraulic Split**	Cycle Time (minutes)	Operating Time (hours)
Date	Nominal	Actual*				
1974						
June	5 682 (1.25)	5 737 (1.13)	1.8 (36)	75/25	1 - 10	79
July	5 000 (1.10)	4 546 (1.0)	1.6 (32)	75/25	2 - 15	90
August	7 046 (1.55)	6 364 (1.40)	2.2 (44)	84/16	5 - 20	62
September	6 364 (1.40)	5 728 (1.26)	2.0 (40)	80/20	5 - 20	85
October	5 228 (1.15)	4 728 (1.04)	1.6 (33)	73/27	5 - 10	74
November	5 910 (1.30)	5 319 (1.17)	1.8 (37)	77/23	5 - 10	72
1975						
May	8 410 (1.85)	7 592 (1.67)	2.6 (53)	80/20	5 - 10	102
June	7 500 (1.65)	6 774 (1.49)	2.3 (47)	74/26	5 - 10	79
June	12 274 (2.70)	11 047 (2.43)	3.8 (77)	76/24	5	14
July	11 820 (2.60)	10 638 (2.34)	3.6 (74)	69/31	5	8
July	7 500 (1.65)	6 774 (1.49)	2.3 (47)	72/28	5	20

* Actual flows were calculated assuming a 5-minute screening cycle.
**Values presented are hydraulic splits at start of a screening cycle.

An additional 119 operating hours were accumulated during final effluent screening in July and August, 1974.

split over a wide range of dry weather flow rates is shown in Table 16. To obtain these data, operations were started with clean screen panels and continued only long enough, at each flow rate, to establish a steady state. To maintain maximum flow rates for extended periods would have required further improvement in the backwash system. With the improved backwash system used in 1975 a maximum nominal flow rate of about 12 274 m^3/d (2.7 mgd) was possible, but manual screen cleaning would likely have been required after about 30 hours of operation.

TABLE 16. RELATIONSHIP BETWEEN HYDRAULIC FLOW RATE AND SPLIT*

Nominal Flow Rate m^3/d (mgd)	Screen Capacity $m^3/m^2 \cdot min$	(gpm/ft^2)	Hydraulic Split Centrate/Concentrate
9 092 (2.0)	3.1	(63)	87/13
9 728 (2.14)	3.3	(68)	86/14
10 319 (2.27)	3.5	(72)	85/15
12 274 (2.70)	4.2	(85)	83/17
14 274 (3.14)	4.9	(99)	82/18
15 138 (3.33)	5.2	(105)	78/22
16 911 (3.72)	5.8	(117)	70/30

*Data were obtained using clean 105-micrometre aperture screen panels and dry-weather raw sewage.

7.3.1.2 Pollutant removal efficiency. Average reductions in SS, VSS, BOD_5, TKN, total P, and settleable solids, calculated on a concentration basis, are presented in Table 17. Pollutant removal values were disappointing for all parameters except settleable solids. The higher SS, VSS, and BOD_5, removals during 1975 may have been due to the higher raw sewage concentrations for this period. It can also be seen in the table that a significant change in flow rate did not bring about a change in pollutant removals. Pollutant removals across the CWC were also estimated on the basis of mass removals, for reasons discussed previously. Overall mass removals for 1974 and 1975 operation are shown in Figure 29. In monthly averages, the percentage mass removal into the concentrate varied from 30 to 48 percent for SS, 35 to 52 percent for VSS, and 22 to

TABLE 17. PERFORMANCE OF CWC DURING DRY WEATHER OPERATION

Year	Actual Capacity m^3/d	(mgd)		Reduction (%)* SS	VSS	BOD_5	TKN	Total P	Settleable Solids	Number of Samples
1974	5 242	(1.17)	Mean	16.5	24	13	9.6	8.7	93	256
			Range	0-54	0-65	0-63	0-44	0-48	14-100	--
1974	8 691	(1.94)	Mean	22.6	28	17	--	--	96	148
			Range	0-62	0-71	0-69	--	--	74-100	--
			Overall Mean	19.3	25.7	14.7	9.6	8.7	94.5	--

*Values calculated on basis of concentration change across screen.

Screen aperture: 105-micrometres

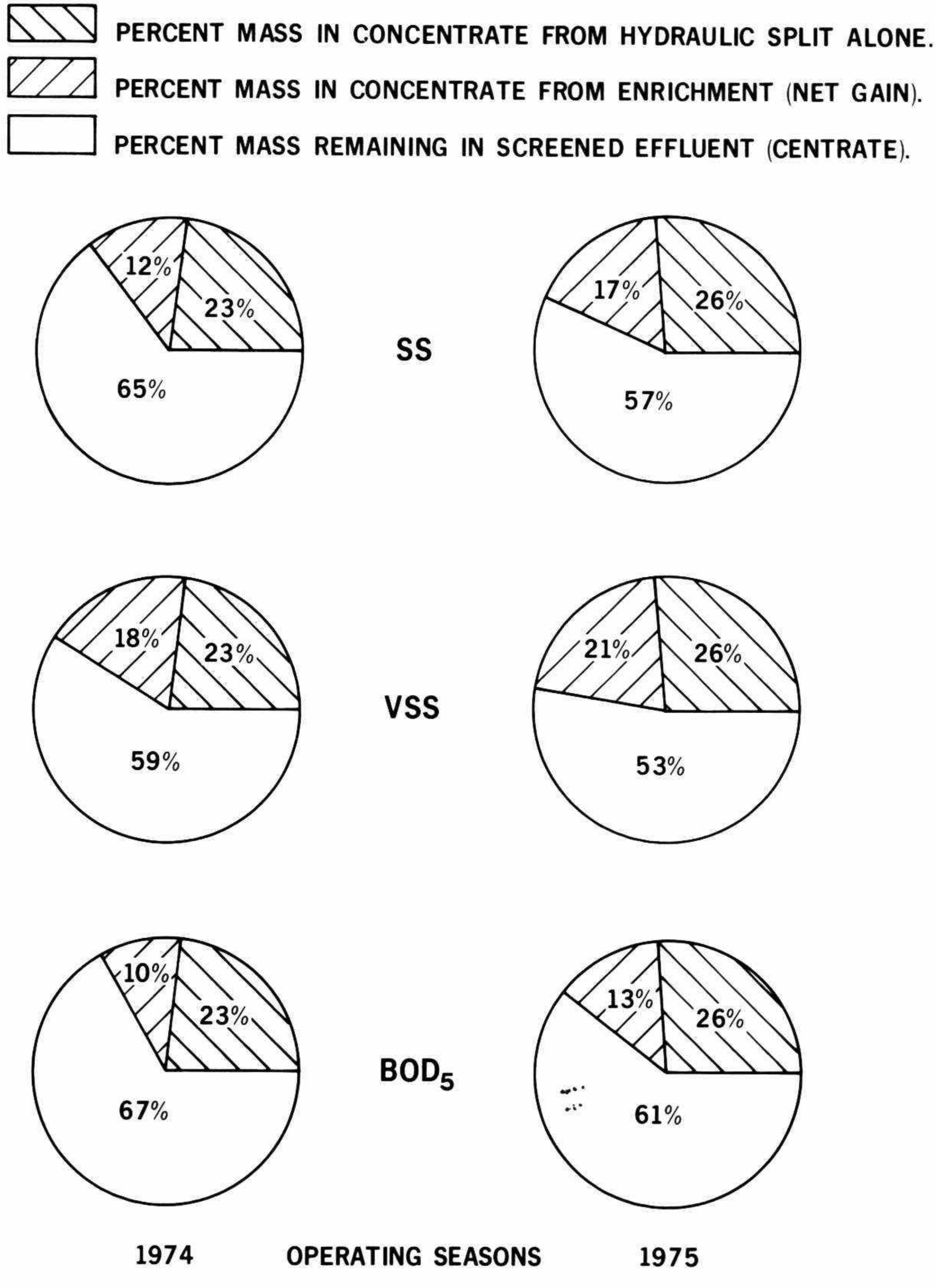


FIGURE 29. POLLUTANT MASS DISTRIBUTION IN CENTRATE AND CONCENTRATE RESULTING FROM SCREENING BY THE CWC IN DRY WEATHER OPERATION

47 percent for BOD_5 (Appendix B, Table B-10). It is readily apparent that the major contribution to mass removal was from hydraulic flow splitting. Average percentage mass removals from concentration increase or enrichment were 12, 18, and 10 percent during 1974, and 17, 21, and 13 percent during 1975, for SS, VSS, and BOD_5, respectively. Corresponding average mass removals by hydraulic flow splitting were 23 percent for 1974 and 26 percent for 1975. During 1975, percentage mass removal both by enrichment and hydraulic flow splitting increased.

Despite higher concentrations of pollutants in the raw sewage in 1975 (Table 14) there were no significant differences between the corresponding concentrations in the centrate in 1974 and 1975. This suggests that concentrations in the centrate may be relatively fixed for a particular screen aperture.

It is evident from the results in Tables 17 and 18 that screen performance did not compare to typical primary clarifier performance. According to the 1974/1975 WPCP Operating Summary, primary clarifier removals at Belleville were of the order 50 to 66 percent for SS and 32 to 36 percent for BOD_5.

The concentrate levels shown in Table 18 confirm the poor enrichment obtained by the CWC during dry weather operation. Settling column tests performed on CWC-concentrate indicated that this material settled as well as or better than the suspended matter in raw sewage (Appendix B).

7.3.2 DSM screen

7.3.2.1 Hydraulic capacity. Hydraulic loading data are given in Table 19. The maximum flow rates to the two screen plates evaluated (305 and 150-micrometre apertures) were 0.78 and 0.54 $m^3/m^2 \cdot min$ (16 and 11 gpm/ft^2), respectively. The 305-micrometre screen operated satisfactorily in conjunction with the mechanical brush; a constant capacity could not be maintained with spray cleaning devices. The 105-micrometre screen plate was not effectively cleaned by either the brush or sprays, and screen blinding plus flooding occurred consistently after about 30 minutes of operation, even at significantly reduced flow rates. The 150-micrometre screen plate was, therefore, considered unsuitable as a raw sewage screening device.

TABLE 18. CWC CENTRATE AND CONCENTRATE CHARACTERISTICS DURING DRY WEATHER OPERATIONS

		Concentration					
		SS (mg/L)	VSS (mg/L)	BOD_5 (mg/L)	TKN (mg/L)	Total P (mg/L)	Settleable Solids (mL/L)
Centrate							
1974	Mean	121	71	76	20	4.7	0.5
	Range	50-285	30-170	5-400	10-43	2.5-8.0	0 - 0.95
	WPCP Mean*	48	--	54	--	--	--
1975	Mean	107	68	66	--	--	0.2
	Range	50-348	20-113	35-140	--	--	0 - 2.2
	WPCP Mean*	44	--	57	--	--	--
Concentrate							
1974	Mean	233	148	96	21	5.0	13.0
	Range	70-1160	15-1120	15-750	11-42	2.5-10.0	3.5-45.0
1975	Mean	199	150	90	--	--	15.0
	Range	93-397	79-260	40-180	--	--	6.5-45.0

*Primary clarifier effluent.

TABLE 19. PERFORMANCE OF DSM SCREEN DURING DRY WEATHER OPERATION - AVERAGE MONTHLY PERCENT REDUCTION AND RANGE

	Percent Reduction**									Screen Capacity		
	SS		VSS		BOD_5		Settleable Solids		Aperture	$m^3/m^2 \cdot min$		Number of
Date	Mean	Range	Mean	Range	Mean	Range	Mean	Range	(micrometres)	(gpm/ft^2)		Samples
1975												
May	14	0-68	17	0-64	9	0-57	68	0-100	305	0.8	(16)	70
June	12	0-30	17	0-34	6	0-47	76	30-100	305	0.8	(16)	47
June*	27	12-35	35	22-55	2	0-10	73	63-91	305	0.5	(11)	12
July*	24	14-55	32	25-56	13	0-42	65	59-74	305	0.5	(11)	22
August	13	2-14	21	5-47	6	0-23	48	44-58	305	0.8	(16)	9
August	8	0-15	12	0-23	5	0-25	-	-	150	0.4	(8)	13
September	20	0-70	25	0-77	15	0-44	70	39-100	150	0.3	(6)	90
October	11	0.27	14	0-27	8	0-43	55	50-60	305	0.8	(16)	51
Mean	12.5		17.3		7.3		62		-	-		-

* Feed to DSM screen with CWC-concentrate.
**Overall average calculated from data obtained with 305-micrometre screen. Percent reductions are arithmetic means.

Operation of the DSM screen as a thickener for CWC-concentrate was discussed in the section on wet weather operations. The hydraulic capacity obtained when the screen was used for this purpose (Table 19) reflects the reduced capacity of the feed pump employed in this experiment rather than reduced screen capacity.

7.3.2.2 Pollutant removal efficiency. Percentage removals of SS, VSS, BOD_5, and settleable solids are presented in Table 19. Pollutant removals by this device were not high, averaging about 12.5 percent for SS and 7.3 percent for BOD_5 when the 305-micrometre screen plate was used. Substitution of the 305-micrometre screen for the 150-micrometre screen did not improve the results.

During periods of June and July when concentrations in the feed to the DSM screen were substantially higher, pollutant removals were also significantly improved. Similar observations were made in the CWC operation. However, there was also a concentration rise in pollutant levels in the effluent (June and July events in Table 20).

Raw sewage and screen effluent concentrations for the parameters SS, VSS, and BOD_5 at five-minute intervals during a two-hour period are presented in Figure 30. Levels of SS and VSS were essentially constant. The peak concentration of BOD_5 in the raw sewage was not effectively removed and possibly represented a slug of soluble material. The variation in raw sewage and screen effluent quality shown in Figure 30 was typical of the Belleville dry weather operation.

Sludge solids concentrations obtained with the 305-micrometre screen plate were of the order three to five percent; all free water dripping from the screen plate was included in the measurements.

7.3.3 Hydrasieve

Performance data obtained with the three screen plates evaluated (1524, 762, and 254-micrometre apertures) are presented in Table 21. Since overall performance with all the three screen plates was poor, only the arithmetic means for SS, VSS, BOD_5, and settleable solids have been included.

Maximum flow rates for the 762 and 254-micrometre screen plates were 0.94 and 0.22 $m^3/m^2 \cdot min$ (19.3 and 4.4 gpm/ft^2), respectively.

TABLE 20. DSM SCREEN EFFLUENT CONCENTRATIONS DURING DRY WEATHER OPERATION

Date	SS (mg/L) Mean	SS (mg/L) Range	VSS (mg/L) Mean	VSS (mg/L) Range	BOD_5 (mg/L) Mean	BOD_5 (mg/L) Range	Settleable Solids (mL/L) Mean	Settleable Solids (mL/L) Range	Aperture (micrometres)
1975									
May	132	60-348	76	43-118	73	36-110	1.2	0.1-4.2	305
June	108	71-170	73	50-115	71	45-110	1.0	0-4.5	305
June*	153	104-203	113	71-158	89	70-140	5.8	1.2-11.5	305
July*	155	118-248	107	82-153	80	55-120	4.8	3.0-7.0	305
August	132	109-260	87	53-129	78	55-120	2.2	1.5-2.5	305
August	119	111-125	72	66- 87	80	70-100	-	-	150
September	138	15-432	89	11-201	84	15-160	2.9	0-9.5	150
October	136	100-213	95	71-136	105	55-215	3.5	3.0-4.0	305
Overall Mean**	127	-	83	-	82	-	2.0	-	-

* Feed to DSM screen was CWC concentrate.
**Data obtained using 150 micrometer screen or CWC concentrate as feed were not included in the calculation of the overall mean

TABLE 21. PERFORMANCE OF THE HYDRASIEVE DURING DRY WEATHER OPERATION

Date	Average Percent Reduction* SS	VSS	BOD5	Settleable Solids	Aperture (micrometres)	Flow Rate $m^3/m^2 \cdot min$ (gpm/ft^2)	Number of Samples
1974							
September	6	6	6	57	254	0.22 (4.4)	7
September	2	4	6	6	1 524	0.94 (19.3)	52
October	8	14	8	65	254	0.22 (4.4)	43
November**	4	6	6	7	762	0.42 (8.5)	33
December	7	10	5	13	762	0.94 (19.3)	62
1975							
May	12	14	7	15	762	0.94 (19.3)	35

* Percent reductions are monthly arithmetic means.
**Feed was applied to screen plate in form of a waterfall.

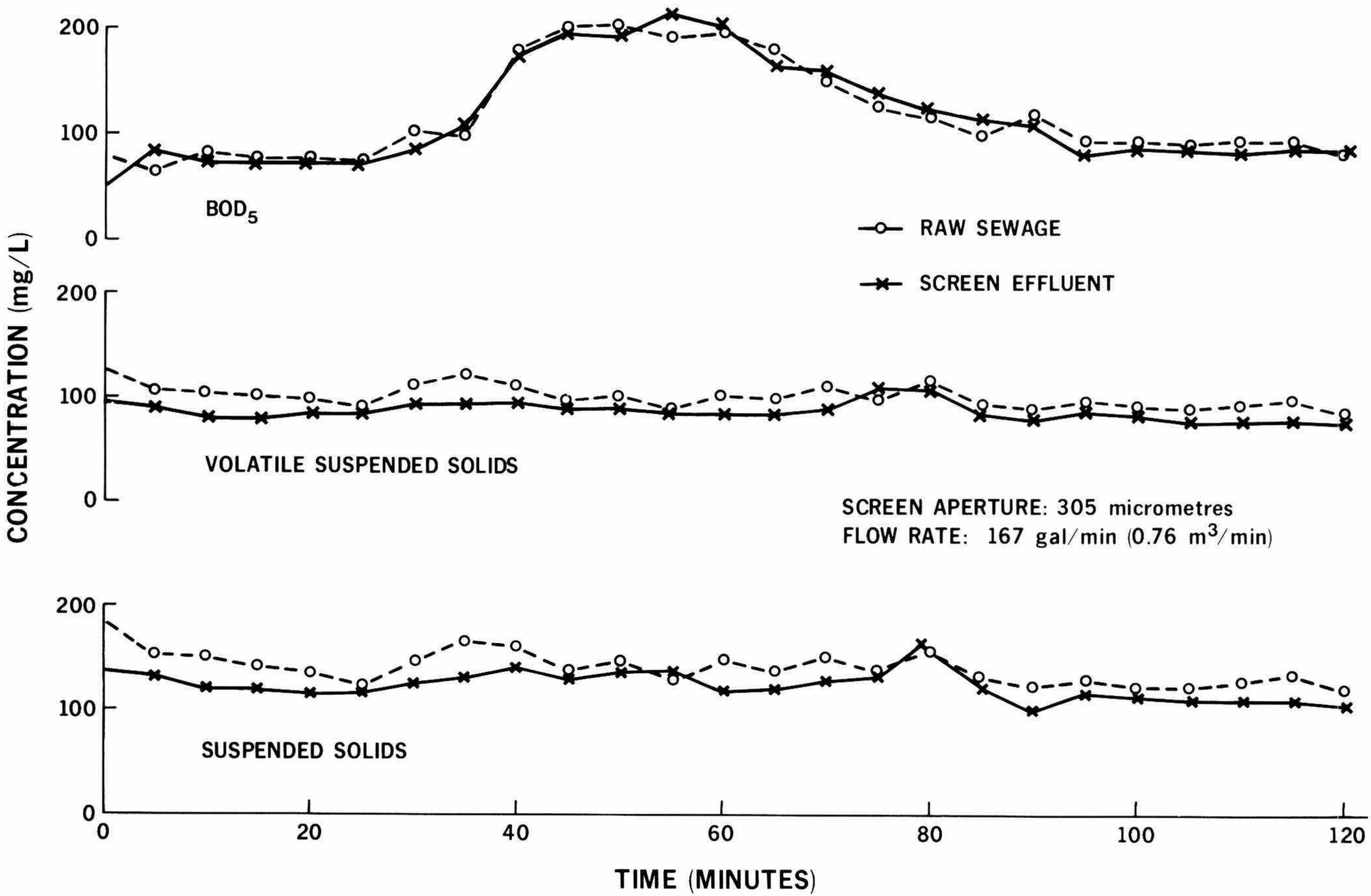


FIGURE 30. CONCENTRATION PROFILE ACROSS DSM SCREEN OCTOBER 2, 1975 - DRY WEATHER OPERATION

The upper hydraulic limit for the 1524-micrometre screen plate, 0.94 $m^3/m^2 \cdot min$ (19.3 gpm/ft^2), was set by the capacity of the inlet distribution chamber and screened effluent discharge section rather than by the screen plate itself.

As already discussed, screen blinding was more pronounced with the finer screen apertures. Blinding was minimized only slightly when the feed to the screen was applied in the form of a waterfall, but this technique reduced hydraulic capacity by half. Pollutant removals were minimal with screen plate. In the absence of automatic screen cleaning devices, the 1524-micrometre plate would be preferred because manual cleaning would be minimized when using the screen as a roughing device.

Sludge concentrations from the 762-micrometre plate, taking into consideration the considerable free water dripping from the screen plate, were about two percent total solids.

7.3.4 Rotostrainer

Data for the Rotostrainer (Table 22) show clearly that pollutant removals were low. Consequently, only the arithmetic means for SS, VSS, BOD_5, and settleable solids removals are presented.

Maximum flow rates, based on the total screen cylinder area, were established during the study period at 1.24 and 0.99 $m^3/m^2 \cdot min$ (25.4 and 20.3 gpm/ft^2) for the 500 and 250 micrometre apeture screen cylinders, respectively. Because of the prevailing low solids concentrations, increased rotational cylinder speeds had no effect on hydraulic capacity. Pollutant removal efficiency was also unaffected by variations in the screen cylinder rotational speed or by changes in flow rate. A decrease in screen aperture size by one half improved settleable solids removal but did not affect removal of SS, VSS, or BOD_5.

This study confirmed the supplier's claim that the screen is best used as a roughing device. Claims for the self-cleaning feature of the Rotostrainer were supported in tests of the 500-micrometre aperture cylinder but not when the 250-micrometre aperture cylinder was used.

Sludge concentrations, including free water dripping from the unit, were of the order 6.5 percent total solids in operations with the 500-micrometre screen cylinder.

TABLE 22. PERFORMANCE OF THE ROTOSTRAINER DURING DRY WEATHER OPERATION

Date	Average Percent Reduction* SS	VSS	BOD_5	Settleable Solids	Aperture (micrometres)	Flow Rate $m^3/m^2 \cdot min$ (gpm/ft^2)	Number of Samples
1975							
August	6	4	7	15	500	0.99 (20.3)	27
September	4	6	9	18	500	0.99 (20.3)	63
October	6	7	4	-	500	1.24 (25.4)	39
October	6	7	6	30	250	0.99 (20.3)	38
November	4	4	3	27	250	0.99 (20.3)	13

* Percent reductions are monthly arithmetic means.

7.4 Summary of Screen Performance

Overall comparisons of the screening devices evaluated are presented in Table 23 and Figure 31. Overall pollutant removals are reported as the arithmetic mean. When more than one screen aperture was evaluated, the operating performance of the most useful screen aperture was selected for the comparison.

For the CWC, mass removals by enrichment only and by enrichment plus hydraulic flow splitting are presented in order to permit realistic comparison with the other devices studied. Because comparison of settleable solids removals is based on the change from raw sewage to screened effluent, by volume (Imhoff cone test), differentiation due to enrichment and flow splitting (CWC) is not felt to be justified.

The relative pollutant removal capabilities of each unit are clearly illustrated in Figure 31. When mass transfer by increased concentration or enrichment is considered, the performance of the CWC is comparable to that of the DSM screen; moderate pollutant removals are achieved. With both the Hydrasieve and Rotostrainer, removals were significantly lower, and these devices can only be considered in roughing applications. These results are similar to those obtained in wet weather performance.

As shown in Table 23, hydraulic loadings were dependent primarily on the type of screening device. Actual loadings ranged from 0.22 to 2.4 $m^3/m^2 \cdot min$ (4.4 to 50 gpm/ft^2). Settleable solids removals were most closely related to screen aperture. Pollutant removals increased significantly when the concentrations in the feed were increased, as illustrated by the performance of the DSM screen in thickening CWC-concentrate.

Concentrations in raw sewage and screen effluents during tests of the CWC and DSM screen are listed in Figure 32. Because pollutant removals by the Hydrasieve and Rotostrainer were not significant no concentration data were included for these devices.

The original objective of comparing treatment provided by screening devices with primary clarification could not be achieved because of the existing WPCP physical layout and operating circumstances, as already

TABLE 23. OVERALL COMPARISON OF SCREENING DEVICES DURING DRY WEATHER OPERATION

Device	Screen Aperture (micrometres)	Hydraulic Loading $m^3/m^2 \cdot min$	Hydraulic Loading (gpm/ft^2)	Percent Pollutant Removals* SS	VSS	BOD_5	Settleable Solids	Sludge** (% Solids)
CWC (Concentration Basis)	105	2.4	(50)	19.3	25.7	14.9	94.5	-
CWC (Enrichment only)	-	-		14.5	19.5	11.5	-	-
CWC (Enrichment and Hydraulic Split)	-	-		39.0	44.0	36.0	-	-
DSM	305	0.8	(16)	12.5	17.3	7.3	62.0	3.5
DSM***	305	0.8	(16)	25.5	33.5	7.5	69.0	5.0
Hydrasieve	762	0.94	(19.3)	7.7	10.0	6.0	11.5	2.0
Rotostrainer	500	1.24	(25.4)	5.3	5.7	4.3	16.5	6.5
Primary Clarifier****	-	-		66/50		36/32		-

* Percent removal figures are overall arithmetic means.
** Sludge - % total solids collected in a container together with water dripping from screen plate.
*** Feed to DSM screen was CWC-concentrate.
****Data from 1974/1975 WPCP operating summary [11].

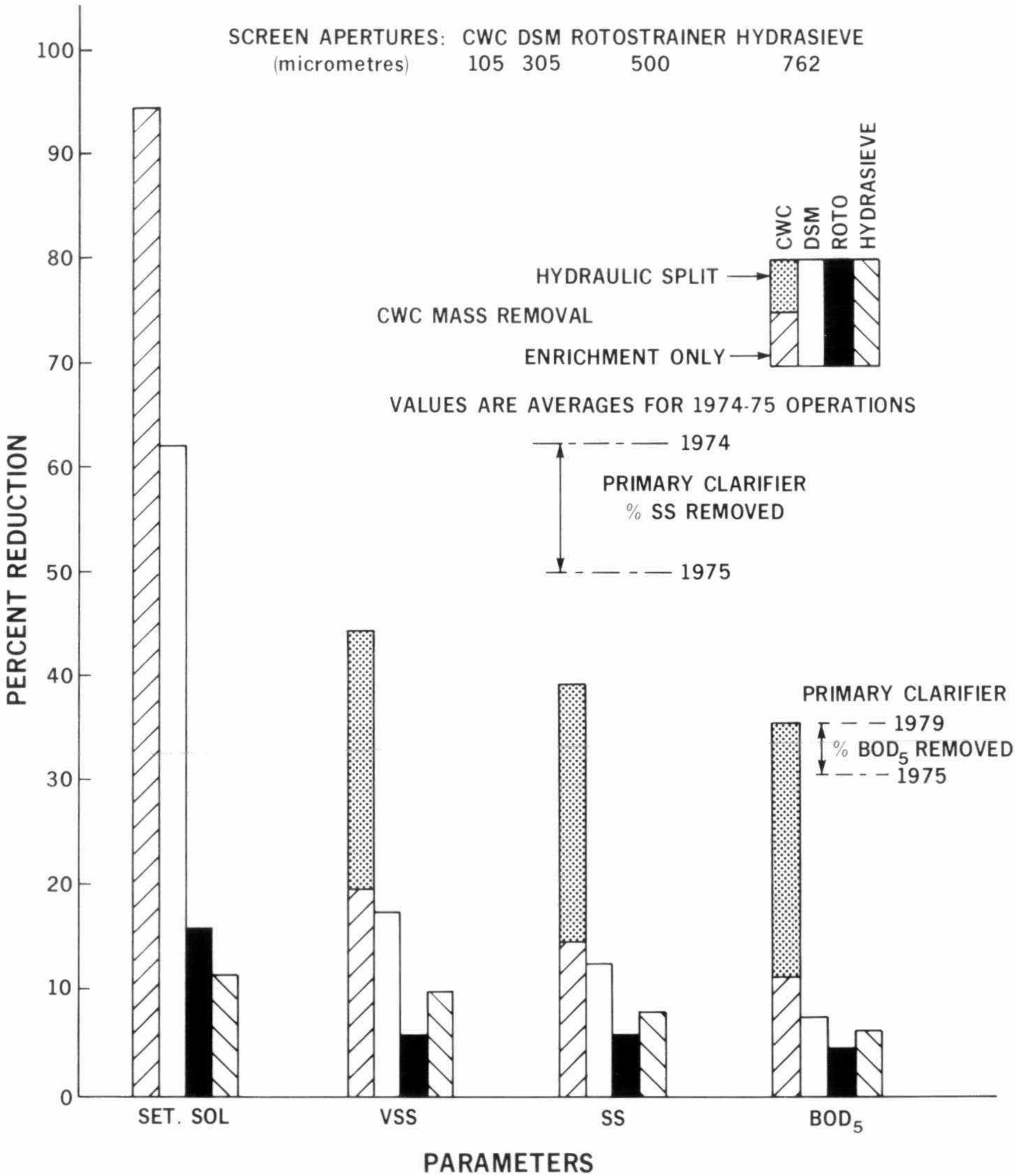


FIGURE 31. PERFORMANCES OF THE SCREENING DEVICES - DRY WEATHER CONDITONS

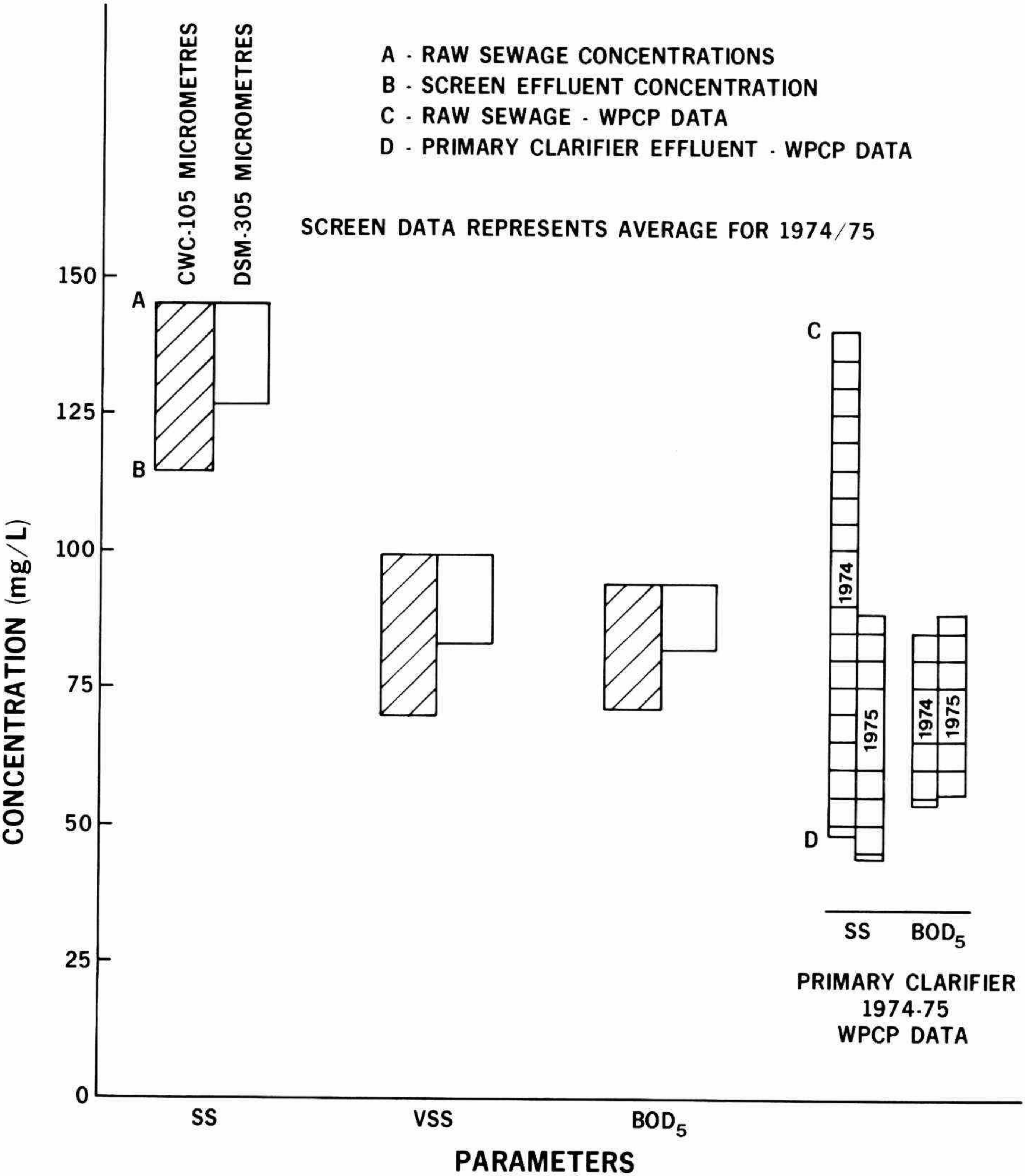


FIGURE 32. CONCENTRATION LEVELS IN EFFLUENTS FROM CWC AND DSM SCREEN - DRY WEATHER OPERATION

discussed. However, to provide some indication of primary clarifier performance, 1974/75 WPCP operating data have been included in Table 23 and Figures 31 and 32. Raw sewage concentration data taken from the WPCP Operating Summary [11] agreed well with data for samples taken for screen evaluation with the exception of the suspended solids levels for 1975. It can be seen in Figure 32 that primary clarifier effluent concentrations were lower than screen effluent concentrations.

7.5 Final Effluent Polishing

During July and August of 1974 the CWC, fitted with 44-micrometre aperture (325-mesh) screen panels, and the associated flotation cell were used for final effluent polishing. A total of 129 operating hours were accumulated during a three-week period. The constant flow-rate of 8410 m^3/d (1.85 mgd) was limited by pumping capacity. Hydraulic split over the fixed 20-minute screening cycle was consistent at 94/6 during the whole study period. The 20-minute cycle was used to prevent possible screen blinding during long-term usage.

The major objective of the effluent polishing study was to investigate the removal of residual suspended matter and soluble BOD_5 and nutrients by screening and foam separation across the CWC and associated flotation cell. During the entire three-week period, total suspended solids levels in the final clarifier effluent fed to the screen were less than 20 mg/L. No reductions in SS, BOD_5, nutrients, or turbidity were achieved by screening and flotation. The large quantities of foam which formed periodically on the flotation tank were not effectively removed by the scum paddle. Accumulated foam was often blown off the tank by the wind. None of the 44-micrometre screen panels was damaged nor was manual screen cleaning required during this study.

8 SUMMARY OF WET AND DRY WEATHER SCREEN OPERATION AND PERFORMANCE

8.1 Pollutant Removals

Screen performances based on percentage mass pollutant removals during wet (first flush) and dry weather operation are shown in Figure 33. The most objective basis for comparison of mass pollutant removal by the four devices evaluated is concentration change or enrichment since the CWC inherently removes additional mass by hydraulic flow splitting. For the other three screening devices, in the absence of screen flooding, percentage mass pollutant removal is identical for all practical purposes to the percentage concentration change across the screen media. Although it is possible to achieve flow splitting with the other screens by tolerating or encouraging flooding, this was not done in the present study because the screens were claimed to be capable of producing sludges, even at substantial hydraulic loading rates. The use of screen apertures finer than those indicated in Figure 33 resulted in significantly reduced hydraulic capacity and severe permanent blinding without additional removal of pollutants.

Relative mass removals by the CWC and DSM screen during dry weather operation were substantially lower than during first flush type storm events. The wet weather data in Figure 33 represent the average of relatively few storms. The number of events for each device was not the same, and parallel operation was limited. In contrast, the dry weather data in Figure 33 were derived from thorough evaluation over many hours. Additional dry and wet weather performance data are presented in Appendix B.

Comparisons based on concentration increase or enrichment reveal that the CWC and DSM screen removed approximately equal quantities of pollutants in wet and in dry weather operation. Removals by the Hydrasieve and Rotostrainer were lower. With the CWC, the mass transferred to the concentrate by flow splitting was substantially larger than that transferred by enrichment alone, during both wet and dry weather operation. Removals during non-first flush storm events were at or below the levels of dry weather performance. No additional removals were achieved by passing CWC-centrate through a flotation tank designed to utilize the dissolved air entrained during the screening process.

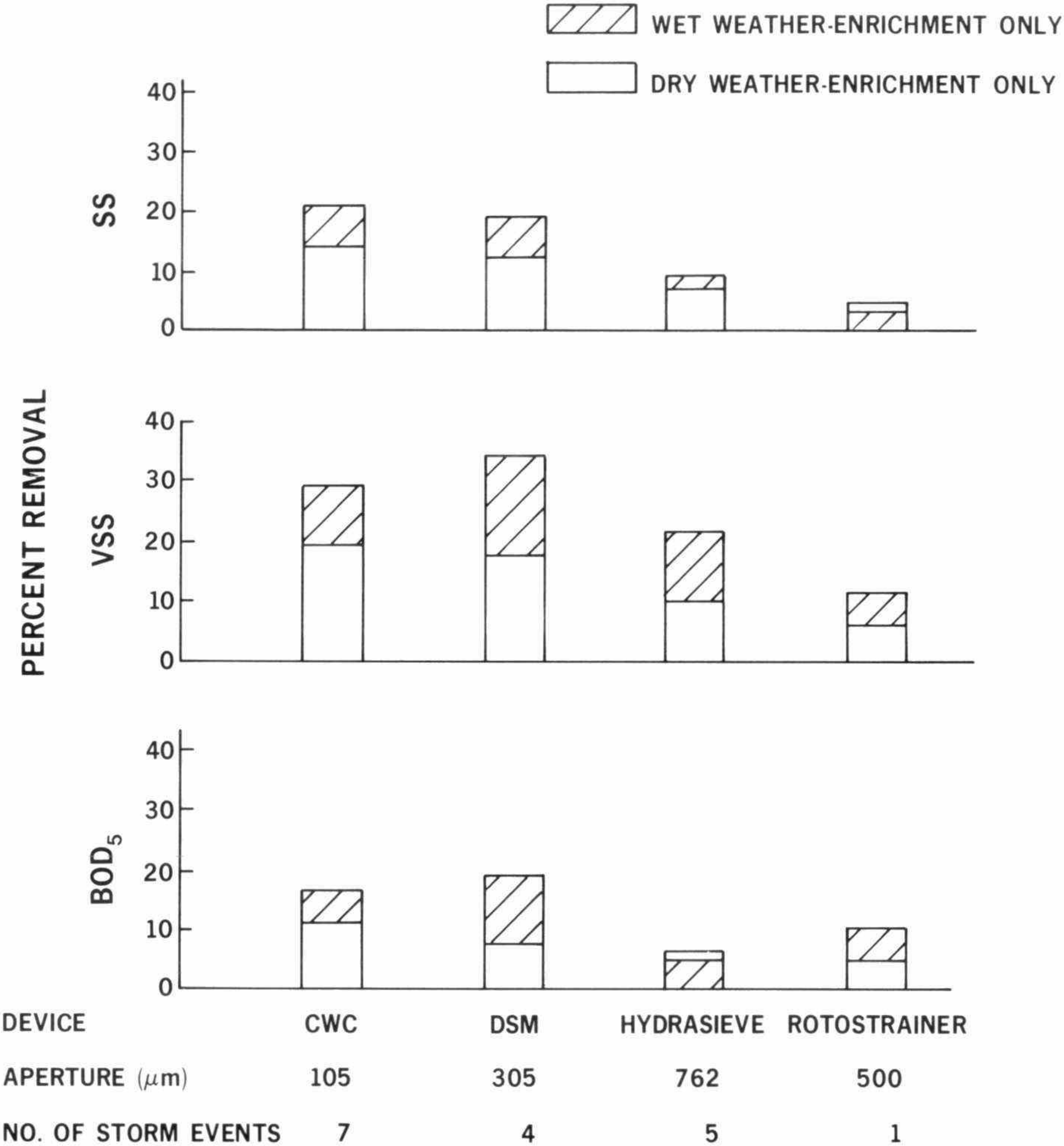


FIGURE 33. OVERALL COMPARISON OF SCREEN PERFORMANCE DURING WET (FIRST FLUSH) AND DRY WEATHER OPERATION

During the study period typical dry weather pollutant removals across the primary clarifier at the Belleville WPCP were in the range 50 to 66 percent for suspended solids and 32 to 36 percent for BOD_5.

8.2 Hydraulic Capacities

Nominal hydraulic screen capacities of the CWC, DSM screen, Hydrasieve, and Rotostrainer were 2.4, 0.78, 0.93 and 1.2 $m^3/m^2 \cdot min$ (50, 16, 19, and 25 gpm/ft^2), respectively. Feasible operating capacities were essentially the same for both wet and dry weather operation. Backwashing reduced the nominal hydraulic capacity of the CWC by 10 percent in wet and five percent in dry weather operation. With the other three screens, actual hydraulic capacities were, for all practical purposes, identical to nominal capacity. During very severe first-flush periods, the CWC hydraulic split temporarily deteriorated below the minimum acceptable ratio (70/30). Under similar conditions, the DSM Screen Hydrasieve also flooded temporarily, regardless of screen condition and with or without automated continuous screen cleaning. Screen flooding of these two devices occurred only for brief periods and was estimated to be a maximum of 10 percent of the influent volume. Rotational adjustment of the Rotostrainer decreased its susceptibility to screen flooding. However, since only one storm event occurred while the Rotostrainer was installed, the wet weather capacity of this unit could not be firmly established. In general, the limited number of storm events during the 1974/75 study period did not allow a thorough wet weather evaluation, for any of the devices, of the effects of applied hydraulic loading and screen aperture on potential screen flooding.

Dry weather hydraulic capacity, including the effect of screen aperture, was extensively studied for each unit. During dry weather operation, no screen flooding should occur at the established flow rate if screen cleaning is adequate. The CWC appears to have the potential for dry weather capacities up to 4.6 $m^3/m^2 \cdot min$ (95 gpm/ft^2); the marginal effectiveness of its backwash system was the main limitation on hydraulic capacity.

8.3 Quality of Screened Effluents

Pollutant concentrations in effluents produced during dry weather operation were less than those obtained under wet (first flush) conditions (Table 24). There was also less variation in effluent quality in dry weather, reflecting the more consistent quality of the influent sewage. Under wet (non-first flush) or dry weather conditions, the dilute quality of the influent sewage was very similar to effluent quality. Over the range of sewage quality encountered in the study, influent and effluent quality tended to rise and fall in parallel; consistent effluent quality was achieved only when influent quality was consistent.

TABLE 24. SCREEN EFFLUENT CONCENTRATIONS DURING WET AND DRY WEATHER OPERATION

Device	Aperture (micrometres)	SS (mg/L)		VSS (mg/L)		BOD_5 (mg/L)		Settleable Solids (mL/L)	
		Wet*	Dry**	Wet	Dry	Wet	Dry	Wet	Dry
CWC	105	360	114	116	69	93	71	2.3	0.4
DSM	305	540	127	169	83	94	82	4.7	2.0
Hydrasieve	762	430	132	138	73	104	84	4.5	2.6
Rotostrainer	500	545	147	173	102	69	98	4.1	6.3

* Wet weather operation: averages for all first flush events.
**Dry weather operation: averages for 1974/75 operation.
Screen operations were not necessarily in parallel.

8.4 Concentrate vs Sludge Production

In normal wet or dry weather operation, the CWC produces a concentrate containing up to 0.1 percent solids. The DSM screen, Hydrasieve, and Rotostrainer produce a disposable sludge containing in the order of 3.5 to 6.5 percent solids, but the solids concentration can be significantly affected by free water dripping from the screen plate or by subsequent drainage of the separated sludge. During periods of temporary flooding of the DSM and Hydrasieve a concentrate containing as low as 1.0 percent solids was produced. However, subsequent natural drainage of the separated solids can produce a disposable sludge.

The CWC-concentrate could theoretically be thickened by second stage screening, but the overall economics of the process would require

careful evaluation. In this study, secondary thickening of dry weather CWC-concentrate was accomplished using the DSM screen. The brief study indicated that DSM screen effluent, which was high in residual pollutants, should likely be recycled to the CWC.

Disposal of the sludges produced by screening was not investigated.

8.5 Anticipated Operating and Maintenance Problems

When the screen cleaning systems performed adequately little day-to-day maintenance was required.

Screen panels of the CWC are prone to damage and should be inspected following major storm events and weekly during continuous dry weather operation. During this study all screening devices were protected by a grit tank, but CWC-screen damage in the form of punctures and tears was frequent. For each damaged screen panel up to 1/36 of the influent volume passed into the screen effluent without receiving treatment. Some types of damage to screen panels can be repaired. During one 440-hour period of essentially dry weather operation, 18 screen panels were damaged, of which 10 could be repaired.

No short-term screen damage is expected with the DSM screen, Hydrasieve, or Rotostrainer. The manufacturers claim for the DSM screen and Hydrasieve a screen life of about 20 years and for the Rotostrainer, 10 years.

Because the CWC backwash system does not prevent permanent screen blinding, periodic manual on-line screen cleaning is required. The frequency of manual cleaning depends on screen usage, raw sewage characteristics, and the condition of the built-in backwash system, including the use of chemical degreasers and hot water.

The reciprocating screen cleaning brush of the DSM screen may require occasional adjustment. Periodically, depending on usage, and after each shutdown, both the front and back of the screen plate must be thoroughly hosed. A chemical degreaser may be needed to clean the screen. Solids buildup on the back side of the screen plate can cause operating problems.

The Rotostrainer is essentially self-cleaning and, if a suitably selected screen aperture is used, no operating problems such as stapling or clogging with fibrous material should occur. The use of too fine an aperture will produce permanent screen stapling with fibrous material. An optional screen backwash is available but it was only used for cleanup following a shutdown. Occasionally, solid matter wedged under the scraper blade impaired screen operation and required attention.

Without a screen cleaning system, the Hydrasieve required operator attention to avoid flooding.

8.6 Screen Application

Based on the results obtained in this study, the CWC and DSM screen have the potential for providing low level treatment to storm flow and dry weather sanitary sewage in combined sewer systems. With the addition of a suitable cleaning system, the Hydrasieve could probably be included in this group. On the basis of its dry weather operation and very limited storm flow data, it was concluded that the Rotostrainer is suitable for aesthetic treatment only. The application of the CWC to secondary WPCP effluent polishing cannot be recommended as no additional pollutant removals were achieved.

In dry weather operation, the overall performance of each screening device was well below the average WPCP primary clarifier performance of 50 to 65 percent suspended solids removal for 1974/75 [11]. Other shortcomings of the screening devices include their inability to concentrate digester supernatant and waste activated sludge. Within the limitations noted, three of the four units may be suitable for dual use as primary treatment devices. The disadvantage of dual operation is that the screen media is not necessarily in peak condition when treatment demands are high during a storm event.

Application of the CWC is limited by the requirement for either further on-site treatment of concentrate or facilities for transmission of the concentrate to a WPCP. A disposable sludge can be produced with the other three units but screen operation may be such that a dilute sludge for transmission to a WPCP would be preferable.

8.7 Screening Costs

Estimates of capital and operating costs are based on 1976 quotations and prevailing labour and utility costs as shown in Appendix C. Although capital costs are fixed for a given installation, operating costs depend largely on the number of operating hours per year and, to a lesser degree, on dry vs wet weather application. A major operating expense with the CWC is screen panel replacement, about three panels per 100 operating hours per unit. Screen replacement should not be a requirement with the other three units. No cost estimate was made for the Hydrasieve.

Screen capacity, attainable wet weather suspended solids removal efficiency, and capital and operating costs are compared in Table 25. Operating cost figures, extracted from Appendix C, are given for three selected screen operating periods per year. It should be noted that actual wet weather screen operating time does not necessarily correspond to runoff time; longer run times could be obtained by storing peak runoff flows for subsequent treatment by screening. The range of 100 to 500 operating hours per year reflects the possible range of wet weather operation; 8000 hours per year corresponds to continuous operation. Detailed variations in operating costs, including the effects of operating time, equipment size, and number of installed units, are shown in Appendix C. The unit volume operating cost of the DSM screen is always less than that for the CWC. Relative to the CWC, the DSM screen operating cost decreases at a faster rate with operating time per year. For example, at 500 hours per year, the operating cost of the DSM screen is less than one-half the CWC operating costs; pollutant removals by each screen are approximately identical. Capital cost per unit volume screened is only slightly higher for the DSM screen.

Dry weather or dual operation should reduce unit operating costs through continuous use (8000 h/annum), but pollutant reductions would be significantly lower. Since the Rotostrainer falls into another screen classification, its costs are not compared with the costs of the CWC and DSM screen.

TABLE 25. SUMMARY OF SCREENING COSTS, CAPACITIES, AND POLLUTANT REMOVALS

	Nominal Capacity				Screening Costs: Capital Cost		Screening Costs: Operating Cost ¢/m3 (¢/1000 gal)			%SS
Device	m^3/d	(mgd)	$m^3/m^2 \cdot min$	(gpm/ft^2)	$\$/1000\ m^3 \cdot d$	(\$/mgd)	8000 h/a	500 h/a	100 h/a	Reduction by Enrichment
1.5-m (60-inch) diameter CWC	8 183	(1.8)	2.5	(50)	4 913	(22 333)	1.5 (7.0)	2.1 (9.5)	4.4 (20.0)	20.6 (55.6*)
1.23-m (4-ft) wide DSM	3 410	(0.75)	0.8	(16)	5 250	(23 867)	0.3 (1.5)	0.8 (3.8)	3.3 (15.0)	19.2
1.23-m (4-ft) wide Rotostrainer	4 546	(1.0)	1.2	(25)	4 772	(21 695)	0.2 (1.0)	1.2 (5.5)	3.3 (15.0)	4.5

*% SS reduction by enrichment plus flow splitting.

ACKNOWLEDGEMENTS

The authors acknowledge the continuous support received during the screening study from staff at the Belleville WPCP, particularly Don Little, Chief Operator, and Stuart Mitton, Plant Electrician. The authors also acknowledge the support received from the staff of the Central MOE and Wastewater Treatment Section Laboratories.

The authors are also indebted, for their support and assistance, to N.K. Mody and J.M. Brooker of Dorr-Oliver-Long, Orillia, P. Knox of SWECO Canada Ltd., D.W. Chorniak of Bauer Bros. Canada Ltd., and L.E. Yeigh of Napier-Reid Ltd.

Special mention is made of Dr. P. Huck and Dr. K.L. Murphy of IEC International Environmental Consultants Ltd. for their review and many valuable suggestions for improvement of the report.

REFERENCES

1. Field, R., "Urban Stormwater Management and Technology, An Assessment", National Environmental Research Centre, U.S. Environmental Protection Agency, Cincinnati, Ohio, May, 1974.

2. International Joint Commission, "Pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River", International Joint Commission, Canada and United States, 1970.

3. "The Problems: One Answer", Symposium on Storm/Sanitary Pollution Control, sponsored by the City of Portland, Oregon, Cornell, Howland, Hayes and Merryfield, and SWECO Inc., June 2, 1970.

4. Talley Jr., "Wastewater Concentration", SWECO Inc., Los Angeles, California, United States Patent 3 707 235, December 1972.

5. Mody, V.K., "High Capacity Stationary DSM Screens for Food Wastewaters", Dorr - Oliver Long Ltd., Orillia, Ontario, 1974.

6. "Hydrasieve Screens", C.E. Bauer Inc., Brantford, Ontario, Bulletin G-240, 1974.

7. Hydracyclonics Corporation, "Rotostrainer - The Self-Cleaning Screen", Bulletin No. RS-250, Lake Bluff, Illinois.

8. Gore and Storrie Ltd., Consulting Engineers, "Report on the City of Belleville Sanitary Sewer System", Project No. 1-0004-66, Toronto, Ontario, 1974.

9. <u>Standard Methods for the Examination of Water and Wastewater</u>, 12th Edition, APHA, AWWA, WPCF, Washington, 1965.

10. "Primary Treatment of Stormwater Overflow from Combined Sewers by High-Rate, Fine-Mesh Screens" (Rotary Fine Screening of Combined Sewer Overflow), Federal Water Quality Administration, U.S. Department of the Interior, Contract 14-12-128, Water Pollution Control Research Series 11023 FDD 03/70.

11. "Operating Summary, Water Pollution Control Projects", Ontario Ministry of the Environment, 1974/1975.

APPENDIX A

EQUIPMENT DEBUGGING

APPENDIX A

EQUIPMENT DEBUGGING

A1 Centrifugal Wastewater Concentrator (CWC)

A1.1 Screen blinding

Immediately upon start-up of this unit for dry weather operation it became evident that the on-line automated screen cleaning system supplied was completely inadequate in preventing screen blinding when treating raw sewage. Investigation revealed that one cause of blinding was "slugs" of industrial oil and grease in the raw sewage. When these slugs were present screen panels could irreversibly blind within approximately 15 minutes. The on-line screen cleaning system was unable to restore screen performance fully, and hydraulic capacity declined as much as 50 percent after 30 hours of operation.

Further studies of the on-line backwash system revealed that the water booster pump was undersized and the hot water supply was insufficient. As a result of these defects temporary screen blinding occurred during the first flush of storm flows. A complete redesign of the cleaning system which included the addition of a continuous backwash cold-water spray whenever the screen was operating was planned. Since components were not immediately available for rebuilding the cleaning system, efforts were made to find interim cleaning techniques that would enable screen evaluation to proceed.

After much experimentation, it was discovered that an engine cleaning compound (GUNK*) applied from an aerosol spray can was very effective for in-place screen cleaning. The need for its routine use was indicated by a significant deterioration of the hydraulic split when the on-line automatic cleaning system could no longer remove built-up residues from the screen panels. The solvent from two 16-oz spray cans sprayed onto the outside of each panel was sufficient to clean all 36 screen panels. After allowing the screen panels to stand for 20 minutes original performance was restored. This procedure was repeated on a weekly basis, about every 30 operating hours, or as needed.

*Radiator Specialty of Canada Ltd., Mississauga, Ontario.

A1.2 Solenoid valve failure

Another problem that resulted in significant screen deterioration in 1974 was failure of the solenoid valves in the backwash system. This problem occurred when the recommended chemical cleaner (ZEP), an emulsifiable solvent which contained ortho-dichlorobenzene and crescylic acid, was used.

The solenoid valves that failed controlled the distribution of hot water for inside and outside screen panel cleaning. The cleaner was added to the hot water at a dilution of 1:200. The recommended wash temperature was 71°C (160°F). Under these service conditions the Buna-N components in the solenoid valves swelled and disintegrated. The substitution of other materials in the valves did not correct the problem.

In the redesign of the backwash systems, it was decided to relocate the solenoid valves to a point upstream of the point where the cleaner was injected, in order to prevent its contact with the valves. The use of ZEP was temporarily abandoned until the changes could be made.

A1.3 Reconstruction of cleaning system

The cleaning system was rebuilt, as described above, prior to the start of operations in 1975. No further problems were encountered, and the cleaning system functioned satisfactorily throughout 1975.

A1.4 Deterioration of screen panel gaskets

In addition to adversely affecting the internal working parts of the wash system solenoid valves, ZEP gradually destroyed the Buna-N screen panel gaskets. Suitable replacement gasket materials were found by evaluating a selection supplied by the manufacturer.

A2 DSM Screen

Although few problems were encountered with this device, it became apparent soon after start-up that the installed spray-wash system was inadequate. As with the CWC, slugs of oil and grease caused screen blinding problems. At the supplier's recommendation the spray system was replaced by a mechanical brush for the rest of the program. The brush was effective with the 305-micrometre aperture screen plate, but ineffective with the next smaller plate, which had 150-micrometre apertures.

Although the top side of the 305-micrometre plate was well cleaned by the mechanical brush, a significant build-up of grease and fibrous material occurred on the underside. Since no automatic cleaning system was available for cleaning the underside of the screen, accumulations were hosed off during regular clean-up periods. It is possible that grease and solids forced through the screen openings by the brush adhered to the underside of the screen plate. It is probable that part of the screen blinding occurred on the underside of the screen plate.

A3 Hydrasieve

The major problem encountered with the Hydrasieve was rapid blinding of the 254-micrometre aperture screen. The frequent manual cleaning that was therefore required prompted a search for ways to minimize the problem. The supplier recommended that feed be applied onto the screen plate in the form of a waterfall. This was accomplished by placing a 100-mm (four-inch) wide board along the overflow lip on top of the screen and adjusting the angle of the board so until the feed hit the screen plate 150-200 mm (6-8 inches) below its top. Screen blinding was slightly reduced by this modification, but hydraulic capacity was decreased by about 50 percent.

Flooding due to screen blinding occurred frequently, particularly with the finer screen openings. Flooding was also a problem during first flush conditions. No satisfactory solution to the flooding problem was found in the course of the study.

A4 Rotostrainer

Although there was initially some concern about the operation of the Rotostrainer because of its slowly rotating drum and other mechanical equipment, few problems were encountered. The screening operation itself kept the drum screen free from grease, oil, and solids at all times. One problem with both the 500 and 250-micrometre aperture cylinders was pullback of the doctor blade from the rotating drum. This allowed solids to slip behind the doctor blade at times and to enter the screen effluent. This problem was not resolved during the test period despite a site visit and blade adjustment by the manufacturer's representative.

When the 250-micrometre screen drum was used considerable fibre "stapling" was observed. Fibres became firmly embedded in the cylinder openings and were difficult to remove. This condition may have been aggravated by slight damage to the screen cylinder that resulted in some parts of the drum not being in contact with the doctor blade.

APPENDIX B

OPERATING DATA

APPENDIX B

OPERATING DATA

This appendix contains precipitation and raw sewage flow data, detailed data on wet weather operation during individual storm events, and monthly summaries of operations in wet and dry weather. Detailed data on dry weather operations are not included because they showed little variation.

Total flow rates of sewage to the WPCP and by-pass flow rates, if any, together with quantities of precipitation for individual storm events are given in Table B-1. Characteristics of raw sewage in dry weather are presented in Table B-2.

Concentration profiles and percentage removals of SS, VSS, BOD_5, settleable solids, COD, TKN, and total P are shown in Tables B-3 to B-8. Data on the three latter parameters for the Hydrasieve and Rotostrainer are not shown. Monthly data on the performances of the units are presented in Tables B-9 to B-15. Concentrations of solvent extractables (oil and grease) from randomly sampled raw sewage, including samples from storm events, are presented in Table B-16. In Table B-17, the settling of suspended matter in raw sewage and CWC-concentrate is compared. Overall pollutant removals of each device, in wet and dry weather operation, are presented in Table B-18.

TABLE B-1. HYDRAULIC FLOWS TO WPCP DURING STORM EVENTS

Date	Time	Total Flow to WPCP m^3/d (mgd)	Secondary By-pass m^3/d (mgd)	Precipitation mm
1974				
July 23	4:00 pm	32 958 (7.25)	0	9.4 mm in 3.0 hours
"	4:30 "	32 958 (7.25)	0	
"	5:30 "	32 958 (7.25)	0	
August 27	11:00 am	67 054 (14.75)	5 683 (1.25)	43 mm in 4.0 hours
"	12:00 "	46 597 (10.25)	1 137 (0.25)	
"	1:00 pm	47 733 (10.50)	1 137 (0.25)	
"	2:00 "	45 460 (10.00)	0	
"	3:00 "	40 914 (9.00)	0	
"	4:00 "	40 914 (9.00)	0	
"	5:00 "	37 505 (8.25)	0	
September 25	11:00 am	27 276 (6.00)	0	7 mm
"	12:00 "	25 685 (5.65)	0	
"	1:00 pm	31 822 (7.00)	0	
"	2:00 "	29 549 (6.50)	0	
"	3:00 "	47 733 (10.50)	1 137 (0.25)	
October 17	9:00 am	56 825 (12.50)	2 273 (0.5)	11 mm
"	9:30 "	40 914 (9.00)	0	
"	10:00 "	38 641 (8.50)	0	
"	10:30 "	38 641 (8.50)	0	
"	11:00 "	37 505 (8.25)	0	
November 12	12:00 am	37 505 (8.25)	0	18 mm
"	1:00 pm	36 368 (8.00)	0	
"	2:00 "	38 641 (8.50)	0	
"	4:00 "	36 368 (8.00)	0	
"	5:00 "	36 368 (8.00)	0	
November 13	2:00 pm	32 958 (7.25)	0	7 mm
"	3:00 "	32 958 (7.25)	0	
"	4:00 "	32 958 (7.25)	0	
"	5:00 "	32 958 (7.25)	0	
November 20	12:00 am	54 552 (12.00)	0	20 mm
"	1:00 pm	59 098 (13.00)	0	
"	1:30 "	61 371 (13.50)	0	
"	2:00 "	82 965 (18.25)	22 730 (5.00)	
"	2:30 "	72 736 (16.00)	22 730 (5.00)	
"	3:00 "	73 873 (16.25)	28 412 (6.25)	
"	3:30 "	56 825 (12.50)	7 956 (1.75)	
"	4:30 "	36 368 (8.00)	0	
"	5:00 "	71 600 (15.75)	15 911 (3.50)	

TABLE B-1. (CONT'D)

Date	Time	Total Flow to WPCP m³/d (mgd)	Flow from Front St. m³/d (mgd)	Secondary By-pass m³/d (mgd)	Precipitation mm
1974					
November 21	9:00 am	63 644 (14.00)	-	20 457 (4.50)	10 mm
"	10:00 "	47 733 (10.50)	-	3 410 (0.75)	
"	11:00 "	56 825 (12.50)	-	11 365 (2.50)	
"	12:00 "	64 780 (14.25)	-	13 638 (3.00)	
"	1:00 "	76 146 (16.75)	-	22 730 (5.00)	
"	2:00 "	59 098 (13.00)	-	7 956 (1.75)	
"	3:00 "	57 962 (12.75)	-	6 819 (1.50)	
"	4:00 "	56 825 (12.50)	-	6 819 (1.50)	
"	5:00 "	54 552 (12.00)	-	2 273 (0.50)	
December 2	12:00 am	36 368 (8.00)	-	0	7 mm
"	1:00 pm	45 460 (10.00)	-	0	
"	2:00 "	40 914 (9.00)	-	0	
"	3:00 "	40 914 (9.00)	-	0	
"	4:00 "	32 958 (7.25)	-	0	
"	5:00 "	32 958 (7.25)	-	0	
1975					
May 30	11:00 am	63 644 (14.00)	41 823 (9.20)	13 638 (3.00)	25 mm in 2.0 hours
"	11:15 "	67 054 (14.75)	45 233 (9.95)	17 048 (3.75)	
"	11:30 "	63 644 (14.00)	46 396 (10.20)	18 184 (4.00)	
"	11:45 "	61 371 (13.50)	39 550 (8.70)	11 365 (2.50)	
"	12:00 "	59 098 (13.00)	37 277 (8.20)	9 092 (2.00)	
"	12:15 pm	59 098 (13.00)	37 277 (8.20)	9 092 (2.00)	
"	12:30 "	55 689 (12.25)	37 505 (8.25)	4 546 (1.00)	
"	12:45 "	55 689 (12.25)	37 505 (8.25)	4 546 (1.00)	
"	1:00 "	45 460 (10.00)	33 186 (7.30)	0	
"	1:30 "	43 187 (9.50)	30 913 (6.80)	0	
June 5	1:00 pm	31 822 (7.00)	20 912 (4.60)	0	20 mm in 3.0 hours
"	2:00 "	29 549 (6.50)	18 639 (4.10)	0	
"	3:00 "	40 914 (9.00)	30 004 (6.60)	0	
"	4:00 "	64 780 (14.25)	52 506 (11.55)	10 229 (2.25)	
"	4:30 "	72 736 (16.00)	59 553 (13.10)	18 184 (4.00)	
"	5:00 "	76 146 (16.75)	62 280 (13.70)	26 140 (5.75)	
"	5:30 "	79 555 (17.50)	62 735 (13.80)	27 276 (6.00)	
"	6:00 "	72 736 (16.00)	55 916 (12.30)	27 276 (6.00)	
"	6:30 "	51 143 (11.25)	34 550 (7.60)	7 956 (1.75)	
"	7:00 "	52 279 (11.50)	35 459 (7.80)	2 273 (0.50)	
"	7:30 "	47 733 (10.50)	30 913 (6.80)	0	
July 9	9:30 am	34 095 (7.50)	-	0	4 mm in 30 minutes
"	10:00 "	34 095 (7.50)	-	0	
"	10:30 "	29 549 (6.50)	-	0	
"	11:30 "	29 549 (6.50)	-	0	
"	12:30 pm	31 822 (7.00)	-	0	

TABLE B-1. (CONT'D)

Date	Time	Total Flow to WPCP m^3/d (mgd)	Flow from Front St. m^3/d (mgd)	Secondary By-pass m^3/d (mgd)	Precipitation mm
1974					
August 25	9:30 am	53 643 (11.80)	29 549 (6.50)	4 546 (1.00)	30 mm in 60 minutes
"	9:45 "	60 008 (13.20)	34 095 (7.50)	10 001 (2.20)	
"	10:00 "	58 189 (12.80)	31 822 (7.00)	3 637 (0.80)	
"	10:15 "	74 554 (16.40)	47 278 (10.40)	24 548 (5.40)	
"	10:30 "	78 191 (17.20)	48 188 (10.60)	24 548 (5.40)	
"	10:45 "	57 280 (12.60)	30 004 (6.60)	7 274 (1.60)	
"	11:00 "	75 464 (16.60)	47 278 (10.40)	18 184 (4.00)	
"	11:15 "	85 465 (18.80)	55 461 (12.20)	33 640 (7.40)	
"	11:30 "	84 101 (18.50)	57 734 (12.70)	31 822 (7.00)	
"	11:45 "	75 464 (16.60)	47 278 (10.40)	10 910 (2.40)	
"	12:00 "	96 375 (21.20)	67 735 (14.90)	30 913 (6.80)	
"	12:15 pm	65 465 (14.40)	37 277 (8.20)	27 276 (6.00)	
"	12:30 "	68 190 (15.00)	40 005 (8.80)	20 457 (4.50)	
"	12:45 "	68 190 (15.00)	40 914 (9.00)	20 457 (4.50)	
"	1:00 "	72 281 (15.90)	43 187 (9.50)	15 456 (3.40)	
"	1:15 "	63 644 (14.00)	34 095 (7.50)	13 638 (3.00)	
"	1:30 "	50 461 (11.10)	23 185 (5.10)	9 092 (2.00)	
"	1:45 "	54 552 (12.00)	31 822 (7.00)	7 728 (1.70)	
"	2:00 "	59 098 (13.00)	40 005 (8.80)	6 364 (1.40)	
"	2:45 "	50 006 (11.00)	30 458 (6.70)	2 273 (0.50)	
"	3:15 "	43 187 (9.50)	26 821 (5.90)	0	

TABLE B-2. SUMMARY OF DRY WEATHER RAW SEWAGE CHARACTERISTICS

Date	SS (mg/L) Mean	SS (mg/L) Range	VSS (mg/L) Mean	VSS (mg/L) Range	BOD_5 (mg/L) Mean	BOD_5 (mg/L) Range	TKN (mg/L) Mean	TKN (mg/L) Range	Total P (mg/L) Mean	Total P (mg/L) Range	Settleabe Solids (mL/L) Mean	Settleabe Solids (mL/L) Range	Number of Samples
1974													
June	119	75-160	80	50-130	90	55-200	20.2	14-34	4.7	3.4-7.6	4.1	2.0-6.5	34
July	140	65-370	91	50-230	102	40-200	17.7	11.31	4.4	3.1-8.4	5.1	0.5-11.0	43
August	152	55-340	103	40-200	68	15-180	19.9	15-40	4.8	2.8-9.2	4.0	0.6-7.0	35
September	154	75-360	98	55-300	82	15-260	22.1	16-36	4.9	2.6-12.0	5.0	2.5-13.0	60
October	138	90-154	89	55-195	85	40-150	21.3	16-33	5.0	3.4-7.0	3.5	1.5-8.7	58
November	152	85-405	88	30-240	96	65-160	19.1	14-32	4.9	3.2-9.8	4.1	0.1-20.0	43
December	126	65-340	68	20-240	85	40-180	18.5	12-43	3.8	2.7-8.4	2.4	0.4-10.5	62
Mean	140	-	88	-	87	-	19.8	-	4.6	-	4.0	-	-
WPCP Mean*	141	-	-	-	85	-	-	-	-	-	-	-	38
1975													
May	154	71-360	95	50-250	79	46-165	-	-	-	-	3.8	1.0-12.0	70
June	129	78-218	95	54-163	79	50-150	-	-	-	-	4.6	1.0-8.0	44
July	138	111-248	97	77-176	84	50-130	-	-	-	-	4.9	3.0-7.0	56
August	142	111-318	102	80-189	78	50-126	-	-	-	-	5.3	4.5-7.5	22
September	164	20-456	118	16-264	101	12-240	-	-	-	-	8.5	0.2-9.5	92
October	153	82-226	113	63-141	112	50-240	-	-	-	-	9.7	7.5-12.0	51
November	187	165-250	149	135-210	174	155-200	-	-	-	-	12.0	11.0-13.0	13
Mean	152	-	110	-	101	-	-	-	-	-	7.0	-	-
WPCP Mean*	88	-	-	-	84	-	-	-	-	-	-	-	40

Mean and range based on hourly grab samples for respective month.

*WPCP mean refers to primary clarifier operation [11].

TABLE B-3. CONCENTRATION PROFILES ACROSS CWC DURING STORM EVENTS (105-micrometre S.S. Screen Cloth)

Sampling Time	SS Raw In. (mg/L)	SS Cent. (mg/L)	SS Conc. (mg/L)	SS Red. %	VSS Raw In. (mg/L)	VSS Cent. (mg/L)	VSS Conc. (mg/L)	VSS Red. %	BOD_5 Raw In. (mg/L)	BOD_5 Cent. (mg/L)	BOD_5 Conc. (mg/L)	BOD_5 Red. %	Settleable Solids Raw In. (mL/L)	Settleable Solids Cent. (mL/L)	Settleable Solids Conc. (mL/L)	Settleable Solids Red. %
June 19/74																
8:00 pm	610	290	595	53	240	90	230	62	130	80	110	38	–	–	–	–
9:00 "	410	240	345	44	205	85	170	59	100	70	130	30	7.5	0.4	7.5	95
July 23/74																
4:30 pm	470	240	530	49	210	100	270	52	170	120	190	29				
5:00 "	590	360	810	39	280	170	420	39	240	150	360	37				
5:30 "	710	380	800	46	260	150	340	42	200	150	280	25				
August 27/74																
11:00 am	115	110	245	4	70	65	175	7	35	35	50	0	1.0	0	14.0	100
12:00 "	90	75	180	17	55	45	130	18	15	20	15	0	0.6	0	10.5	100
1:00 pm	90	80	145	11	60	50	105	17	35	35	45	0	1.0	0	7.0	100
2:00 "	150	115	190	23	65	50	105	23	25	40	25	0	1.5	0	5.0	100
3:00 "	240	255	295	0	65	50	100	23	30	30	30	0	1.0	0.1	5.0	99
4:00 "	145	120	100	17	55	45	75	18	20	20	80	0	1.0	0.1	4.5	99
5:00 "	125	115	160	8	60	50	90	17	50	50	60	0	–	–	–	–
September 25/74																
11:00 am	235	230	370	2	180	155	300	14	50	45	50	10	15.0	13.0	32.5	13
12:00 "	140	105	200	25	110	75	70	32	50	50	40	0	5.0	0.1	16.5	98
1:00 pm	245	175	315	29	155	100	205	35	60	65	60	0	5.5	0.2	12.0	96
2:00 "	275	235	365	15	160	120	230	25	45	40	50	11	8.5	1.7	14.0	80
3:00 "	225	160	275	29	140	90	180	36	95	85	100	11	4.0	0.1	5.0	98
October 17/74																
8:30 am	345	230	420	33	130	85	195	35	40	35	40	13	–	–	–	–
9:00 "	290	230	560	21	95	60	300	37	50	45	50	10	3.0	0.5	7.5	83
9:30 "	210	185	290	12	75	60	90	20	45	40	40	11	–	–	–	–
10:00 "	305	260	385	15	100	80	155	20	60	55	55	8	3.0	0.3	8.5	90
10:30 am	228	190	288	17	93	70	143	25	65	70	70	0	–	–	–	–
11:00 am	150	120	190	20	85	60	130	29	70	80	70	0	3.0	0.1	8.0	97

TABLE B-3. (CONT'D)

Sampling Time	SS				VSS				BOD_5				Settleable Solids			
	Raw In. (mg/L)	Cent. (mg/L)	Conc. (mg/L)	Red. %	Raw In. (mg/L)	Cent. (mg/L)	Conc. (mg/L)	Red. %	Raw In. (mg/L)	Cent. (mg/L)	Conc. (mg/L)	Red. %	Raw In. (mL/L)	Cent. (mL/L)	Conc. (mL/L)	Red. %
November 12/74																
12:00 am	310	255	410	18	155	115	200	26	130	110	150	15	4.5	2.4	11.5	47
1:00 pm	315	300	365	6	155	125	85	19	145	130	180	10	3.0	1.2	7.5	60
2:00 "	205	185	240	10	15	50	15	0	95	80	100	16	–	–	–	–
4:00 "	430	340	510	21	70	30	130	56	140	110	130	21	3.8	0.4	7.0	90
5:00 "	285	235	315	18	70	30	35	56	90	90	85	0	–	–	–	–
November 13/74																
2:00 pm	330	260	360	21	95	75	135	21	180	160	170	11	2.0	0.4	7.0	80
3:00 "	125	110	120	12	60	35	40	42	110	85	140	24	2.5	0	9.5	100
4:00 "	145	135	150	7	95	85	100	11	130	120	130	8	2.5	0	8.5	100
5:00 "	220	120	160	45	155	10	75	94	100	90	100	10	–	–	–	–
November 20/74																
1:00 pm	280	240	345	14	100	70	135	30	65	55	110	15	2.0	0.2	7.0	90
1:30 "	310	250	435	19	115	70	175	39	70	50	55	28	–	–	–	–
2:00 "	710	450	765	37	250	140	275	44	110	80	120	27	7.0	2.2	8.0	69
2:30 "	410	305	470	26	150	95	200	37	70	80	90	0	–	–	–	–
3:00 "	285	220	310	23	100	60	115	40	75	35	60	53	2.0	0.1	4.5	95
November 21/74																
9:00 am	120	90	175	25	60	35	95	42	60	50	70	17	1.8	0	6.5	100
10:00 am	130	100	200	23	65	40	110	38	90	70	95	22	0.3	0	5.5	100
11:00 am	120	95	185	21	55	45	105	18	70	90	110	0	0.8	0	5.0	100
12:00 am	130	100	175	23	65	35	30	46	50	45	60	10	0.8	0	5.0	100
1:00 pm	145	80	115	45	30	30	65	0	35	40	55	0	0.4	0	4.5	100
2:00 pm	285	215	420	25	150	95	210	37	95	110	80	0	4.5	1.0	9.5	100
3:00 pm	85	130	70	0	45	55	30	0	55	65	50	0	4.5	1.0	9.5	78
4:00 pm	95	75	115	21	50	35	70	30	75	70	70	7	0.5	0	2.5	100
5:00 pm	85	70	135	18	55	40	95	27	55	55	70	0	–	–	–	–

TABLE B-3. (CONT'D)

Sampling Time	SS				VSS				BOD_5				Settleable Solids			
	Raw In. (mg/L)	Cent. (mg/L)	Conc. (mg/L)	Red. %	Raw In. (mg/L)	Cent. (mg/L)	Conc. (mg/L)	Red. %	Raw In. (mg/L)	Cent. (mg/L)	Conc. (mg/L)	Red. %	Raw In. (mL/L)	Cent. (mL/L)	Conc. (mL/L)	Red. %
May 30/75																
11:00 am	1720	960	1420	44	550	250	455	54	200	170	190	15	19.0	6.5	18.0	66
11:15 "	938	728	1003	22	350	195	330	44	150	100	110	33	-	-	-	-
11:30 "	926	605	749	35	236	129	245	45	80	65	85	19	-	-	-	-
11:45 "	509	395	569	22	198	107	232	46	75	70	90	7	-	-	-	-
12:00 "	465	276	441	41	177	86	184	51	85	40	85	53	6.5	1.3	10.5	80
12:15 pm	410	240	420	41	170	84	180	51	80	50	90	38	-	-	-	-
12:30 "	360	226	362	37	172	83	169	52	75	60	95	20	-	-	-	-
12:45 "	309	200	312	35	170	80	171	53	70	60	85	14	-	-	-	-
June 5/75																
4:00 pm	721	486	733	33	297	166	400	44	130	110	130	15	-	-	-	-
4:30 "	577	444	524	23	220	151	218	31	120	100	130	17	11.5	3.8	14.0	67
5:00 "	724	595	1023	18	212	156	306	26	140	130	140	7	9.0	2.6	11.0	71
5:30 "	861	637	914	26	247	150	313	39	100	75	90	25	-	-	-	-
6:00 "	649	439	631	32	223	122	251	45	80	80	85	0	-	-	-	-
6:30 "	631	320	521	49	199	97	221	51	95	70	80	26	6.5	1.3	10.0	80
7:00 "	359	225	359	37	153	74	177	52	90	60	100	33	-	-	-	-
July 9/75																
9:30 am	811	542	970	33	351	190	461	46	180	120	230	33	10.0	6.0	24.0	40
10:00 am	674	526	845	22	322	189	431	41	140	100	270	28	-	-	-	-
10:30 am	339	283	371	17	183	127	233	31	100	85	110	15	7.5	3.5	15.0	53

TABLE B-4. CONCENTRATION PROFILES ACROSS CWC DURING STORM EVENTS

	COD				TKN				TOTAL P			
Sampling Time	Raw In. (mg/L)	Cent. (mg/L)	Conc. (mg/L)	Red. %	Raw In. (mg/L)	Cent. (mg/L)	Conc. (mg/L)	Red. %	Raw In. (mg/L)	Cent. (mg/L)	Conc. (mg/L)	Red. %
November 12/74												
12:00 am	350	290	440	17	25	25	32	0	7.0	5.0	8.0	28
1:00 pm	440	370	520	16	20	23	20	0	5.5	5.5	6.0	0
2:00 "	340	230	330	32	19	18	20	5	4.9	4.5	5.0	8
4:00 "	440	530	460	0	22	23	21	0	6.0	6.5	6.0	0
5:00 "	300	260	310	13	17	17	18	0	3.4	4.4	3.7	0
November 13/74												
2:00 pm	300	290	390	3	17	18	18	0	3.4	3.0	4.0	13
3:00 "	190	150	270	21	17	16	18	6	8.0	3.6	4.1	55
4:00 "	270	240	220	11	18	17	17	6	4.4	4.6	4.8	0
5:00 "	110	110	250	0	15	15	17	0	3.7	3.6	3.9	3
November 20/74												
1:00 pm	240	240	260	0	14	13	14	7	3.3	2.9	3.3	12
1:30 "	210	150	290	29	14	13	15	7	3.5	3.0	3.7	14
2:00 "	480	250	420	48	21	16	21	24	6.1	4.7	6.2	23
2:30 "	290	230	280	21	16	14	14	12	4.5	3.4	4.3	24
3:00 "	180	150	250	17	11	11	12	0	3.0	2.8	3.5	7
November 21/74												
9:00 am	150	240	350	0	18	18	19	0	3.0	2.8	3.3	7
10:00 "	370	180	300	51	15	13	15	13	3.1	2.8	3.3	10
11:00 "	170	140	170	18	11	11	22	0	2.6	2.5	2.8	4
12:00 "	150	160	170	0	9	9	10	0	2.5	2.5	2.9	0
1:00 pm	90	90	110	0	11	10	11	9	2.1	1.7	2.3	19
2:00 "	300	310	420	0	17	15	18	12	3.4	3.8	4.3	3
3:00 "	130	210	160	0	11	12	12	0	2.4	2.3	2.3	4
4:00 "	210	200	240	5	13	9	10	31	2.4	2.1	2.3	12
5:00 "	140	100	160	29	9	9	10	0	1.8	1.9	2.2	0

TABLE B-4. (CONT'D)

Sampling Time	COD Raw In. (mg/L)	COD Cent. (mg/L)	COD Conc. (mg/L)	COD Red. %	TKN Raw In. (mg/L)	TKN Cent. (mg/L)	TKN Conc. (mg/L)	TKN Red. %	TOTAL P Raw In. (mg/L)	TOTAL P Cent. (mg/L)	TOTAL P Conc. (mg/L)	TOTAL P Red. %
May 30/75												
11:00 am	1640	900	1060	45	39	29	31	26	6.3	5.6	6.4	11
11:15 "	960	480	780	50	28	22	26	21	5.1	5.8	5.3	0
11:30 "	500	320	480	36	20	18	20	10	3.2	2.5	5.3	22
11:45 "	490	280	470	43	19	18	21	5	3.4	3.3	4.5	3
12:00 "	360	350	470	3	22	14	19	36	3.3	3.5	4.0	0
12:15 pm	370	300	380	19	20	14	18	30	3.6	3.6	4.2	0
12:30 "	350	250	380	29	18	14	15	22	4.0	3.8	4.2	5
12:45 "	380	230	320	40	15	14	16	7	4.3	3.4	4.4	21
June 5/75												
4:30 pm	660	500	830	24	21	20	24	5	4.3	5.0	5.7	0
5:00 "	460	580	820	0	22	17	20	23	4.2	6.6	5.1	0
5:30 "	490	380	670	22	20	15	19	25	6.4	5.0	2.8	22
6:00 "	500	300	600	40	21	16	21	24	3.8	3.3	4.0	13
6:30 "	450	320	540	29	20	15	17	25	5.5	3.7	3.8	33
7:00 "	340	220	380	35	17	14	18	18	3.4	2.8	3.7	18
July 9/75												
9:30 am	750	600	1770	20	33	29	38	15	8.3	6.6	10.0	8
10:00 "	660	470	780	29	29	29	33	0	6.9	6.6	8.6	4
10:30 "	470	370	580	21	27	25	26	7	5.1	4.9	4.9	6

TABLE B-5. CONCENTRATION PROFILES ACROSS DSM SCREEN DURING STORM EVENTS (305-micrometre screen aperture)

Sampling Time	SS Raw Influent (mg/L)	SS Screen Effluent (mg/L)	SS Red. %	VSS Raw Influent (mg/L)	VSS Screen Effluent (mg/L)	VSS Red. %	BOD_5 Raw Influent (mg/L)	BOD_5 Screen Effluent (mg/L)	BOD_5 Red. %	Settleable Solids Raw Influent (mL/L)	Settleable Solids Screen Effluent (mL/L)	Settleable Solids Red. %
May 30/75												
11:00 am	1720	1460	15	550	370	33	200	180	10	19.0	9.5	50
11:15 "	938	759	19	350	206	41	150	110	27	-	-	-
11:30 "	926	752	19	236	167	29	80	85	0	-	-	-
11:45 "	509	426	16	198	131	34	75	70	7	-	-	-
12:00 "	465	345	26	177	108	39	85	70	18	6.5	1.8	72
12:15 pm	410	298	27	170	97	43	80	70	13	-	-	-
12:30 "	360	243	33	172	86	50	75	70	7	-	-	-
12:45 "	309	222	27	170	72	58	70	55	21	-	-	-
June 5/75												
4:00 pm	721	599	17	297	208	30	130	120	8	-	-	-
4:30 "	577	508	12	220	174	21	120	100	17	11.5	4.5	61
5:00 "	724	706	3	212	178	16	140	140	0	9.0	4.0	56
5:30 "	861	737	14	247	179	27	100	90	10	-	-	-
6:00 "	649	494	24	223	137	39	80	80	0	-	-	-
6:30 "	631	350	45	199	104	47	95	85	11	6.5	1.7	74
7:00 "	359	275	23	153	97	37	90	60	33	-	-	-
July 9/75 (Feed was CWC Concentrate)												
9:30 am	970	776	20	461	294	36	230	150	35	24.0	9.0	63
10:00 "	845	525	38	431	173	60	270	120	56	-	-	-
10:30 "	371	286	23	233	148	36	110	80	27	15.0	4.8	68

TABLE B-5. (CONT'D)

Sampling Time	SS Raw Influent (mg/L)	SS Screen Effluent (mg/L)	SS Red. %	VSS Raw Influent (mg/L)	VSS Screen Effluent (mg/L)	VSS Red. %	BOD_5 Raw Influent (mg/L)	BOD_5 Screen Effluent (mg/L)	BOD_5 Red. %	Settleable Solids Raw Influent (mL/L)	Settleable Solids Screen Effluent (mL/L)	Settleable Solids Red. %
August 25/75												
9:45 am	357	428	0	211	208	1	70	60	14	-	-	-
10:00 "	1250	1300	0	340	270	21	140	135	4	7.3	3.5	59
10:15 "	1230	1180	4	330	270	18	115	140	0	-	-	-
10:30 "	940	895	5	314	257	18	110	185	0	11.0	7.5	32
10:45 "	994	742	27	476	259	46	180	150	20	-	-	-
11:00 "	580	505	13	255	160	37	95	70	26	5.7	3.5	39
11:15 "	431	413	4	156	126	19	70	65	7	-	-	-
11:30 "	339	350	0	127	100	21	50	40	20	4.5	2.5	44
11:45 "	358	259	28	128	115	10	46	56	0	-	-	-
12:00 "	441	405	8	150	121	19	44	46	0	3.9	2.8	28
12:15 pm	449	501	0	143	125	13	70	60	0	-	-	-
12:30 "	580	566	2	191	155	19	75	55	27	2.1	1.3	38
12:45 "	480	453	6	160	124	23	58	46	21	-	-	-
1:00 "	396	321	19	145	94	35	36	38	0	4.1	1.4	66
1:15 "	355	325	8	120	92	23	36	36	0	-	-	-
1:30 "	325	323	1	100	90	10	36	36	0	3.5	2.5	29
1:45 "	280	286	0	95	85	11	38	43	0	-	-	-

TABLE B-6. CONCENTRATION PROFILES ACROSS DSM SCREEN DURING STORM EVENTS

	SS			TKN			Total P		
Sampling Time	Raw Influent (mg/L)	Screen Effluent (mg/L)	Red. %	Raw Influent (mg/L)	Screen Effluent (mg/L)	Red. %	Raw Influent (mg/L)	Screen Effluent (mg/L)	Red. %
May 30/75									
11:00 am	1 640	1 820	0	39	33	15	6.3	8.0	0
11:15 "	960	580	40	28	21	25	5.1	5.0	2
11:30 "	500	450	10	20	18	10	3.2	2.1	34
11:45 "	490	310	37	19	18	5	3.4	3.1	9
12:00 "	360	310	14	22	16	27	3.3	3.7	0
12:15 pm	370	300	19	20	15	25	3.6	3.7	0
12:30 "	350	290	17	18	15	16	4.0	3.8	5
12:45 "	380	250	34	15	14	7	4.3	3.7	14
June 5/75									
4:30 pm	660	510	8	21	21	0	4.3	5.2	0
5:00 "	460	700	0	22	18	18	4.2	6.7	0
5:30 "	490	440	10	20	17	15	6.4	4.4	31
6:00 "	500	330	34	21	16	24	3.8	3.7	3
6:30 "	450	320	29	20	15	25	5.5	3.7	33
7:00 "	340	280	18	17	15	12	3.4	2.8	18
July 9/75									
9:30 am	750	680	9	33	36	0	8.3	9.2	0
10:00 "	660	570	14	29	32	0	6.9	7.7	0
10:30 "	470	390	17	27	25	7	5.1	4.8	6
August 25/75									
9:45 am	545	545	0	39	41	0	5.9	7.0	0
10:00 "	685	610	11	27	26	4	3.1	6.5	0
10:15 "	625	580	7	24	25	0	5.6	3.1	45
10:30 "	685	535	23	27	26	4	4.7	5.9	0
10:45 "	800	415	48	26	23	12	6.6	4.0	39

TABLE B-6. (CONT'D)

Sampling Time	SS Raw Influent (mg/L)	SS Screen Effluent (mg/L)	SS Red. %	TKN Raw Influent (mg/L)	TKN Screen Effluent (mg/L)	TKN Red. %	Total P Raw Influent (mg/L)	Total P Screen Effluent (mg/L)	Total P Red. %
August 25/75 (cont'd)									
11:00 "	375	335	11	20	17	15	5.9	4.8	5
11:15 "	340	325	4	16	16	0	4.4	4.3	2
11:30 "	325	260	20	14	14	0	3.6	3.5	3
11:45 "	200	300	0	16	16	0	4.4	4.1	7
12:00 "	385	300	22	17	16	6	4.5	4.5	0
12:15 pm	340	310	9	19	19	0	4.1	3.9	5
12:30 "	320	390	0	23	23	0	5.0	6.2	0
12:45 "	310	300	3	19	19	0	4.6	5.6	0
1:00 "	300	220	27	14	15	0	4.1	5.0	0
1:15 "	285	250	12	12	13	0	3.5	4.1	0
1:30 "	270	285	0	11	12	0	2.9	3.2	0
1:45 "	270	270	0	12	12	0	3.2	3.2	0

TABLE B-7. CONCENTRATION PROFILES ACROSS HYDRASIEVE DURING STORM EVENTS (762-micrometre screen aperture)

Sampling Time	SS			VSS			BOD_5			Settleable Solids		
	Raw Influent (mg/L)	Screen Effluent (mg/L)	Red. %	Raw Influent (mg/L)	Screen Effluent (mg/L)	Red. %	Raw Influent (mg/L)	Screen Effluent (mg/L)	Red. %	Raw Influent (mL/L)	Screen Effluent (mL/L)	Red. %
October 17/74*												
8:30 am	345	300	13	130	90	30	40	40	0	–	–	–
9:00 "	290	265	9	95	70	26	50	50	0	3.0	1.2	60
9:30 "	210	200	5	75	70	7	45	45	0	–	–	–
10:00 "	305	290	5	100	90	10	60	65	0	3.0	1.2	60
10:30 "	228	215	5	93	85	8	65	65	0	–	–	–
11:00 "	150	140	7	85	80	6	70	60	14	3.0	1.5	50
November 12/74												
12:00 am	310	290	6	155	130	16	130	130	0	4.5	4.5	0
1:00 pm	315	295	6	155	135	13	145	150	0	3.0	3.5	0
2:00 "	205	200	3	15	35	0	95	90	5	–	–	–
4:00 "	430	445	0	70	15	79	140	160	0	3.8	3.5	8
5:00 "	285	280	2	70	40	43	90	90	0	–	–	–
November 13/74												
2:00 pm	330	320	3	95	95	0	180	200	0	–	–	–
3:00 "	125	115	8	60	10	83	110	95	14	2.0	2.0	0
4:00 "	145	120	17	95	85	11	130	140	0	2.5	2.0	20
5:00 "	220	185	16	155	95	39	100	90	10	2.5	2.5	0
November 20/74												
1:00 pm	280	290	0	100	100	0	65	75	0	2.0	1.8	10
1:30 "	310	310	0	115	105	9	70	60	14	–	–	–
2:00 "	710	620	13	250	205	18	110	100	9	7.0	5.2	26
2:30 "	410	365	11	150	130	13	70	90	0	–	–	–
3:00 "	285	290	0	100	105	0	75	45	40	2.0	1.5	25

*Screen with 254-micrometre aperture was used during this event.

TABLE B-7. (CONT'D)

	SS			VSS			BOD_5			Settleable Solids		
Sampling Time	Raw Influent (mg/L)	Screen Effluent (mg/L)	Red. %	Raw Influent (mg/L)	Screen Effluent (mg/L)	Red. %	Raw Influent (mg/L)	Screen Effluent (mg/L)	Red. %	Raw Influent (mL/L)	Screen Effluent (mL/L)	Red. %
<u>November 21/74</u>												
9:00 am	120	105	12	60	50	17	60	60	0	1.8	2.0	0
10:00 "	130	140	0	65	60	8	90	90	0	0.3	1.5	0
11:00 "	120	125	0	55	65	0	70	55	21	0.8	1.0	0
12:00 "	130	130	0	65	65	0	50	60	0	0.8	0.8	0
1:00 pm	145	95	34	30	35	0	35	35	0	0.4	0.4	0
2:00 "	285	275	4	150	145	3	95	120	0	4.5	3.5	22
3:00 "	85	90	0	45	45	0	55	60	0	0.5	1.5	0
4:00 "	95	95	0	50	50	0	75	70	7	0.1	0.1	0
5:00 "	85	80	6	55	50	9	55	55	0	–	–	–
<u>December 2/74</u>												
12:00 am	240	230	4	115	110	4	90	90	0	3.5	3.5	0
1:00 pm	505	520	0	230	205	11	160	170	0	5.2	4.0	23
2:00 "	250	235	6	120	95	21	100	110	0	3.0	2.8	7
<u>May 30/75</u>												
11:00 am	1720	1380	19	550	360	35	200	140	30	19.0	11.0	42
11:15 "	938	792	16	350	245	30	150	130	13	–	–	–
11:30 "	926	792	14	236	192	19	80	85	0	–	–	–
11:45 "	509	440	14	198	148	25	75	75	0	–	–	–
12:00 "	465	369	21	177	131	26	85	80	6	6.5	3.0	54
12:15 pm	410	318	22	170	116	31	80	75	6	–	–	–
12:30 "	360	264	27	172	104	40	75	70	7	–	–	–
12:45 "	309	213	31	170	98	42	70	55	21	–	–	–
<u>June 5/75</u>												
4:30 pm	577	509	12	220	194	12	120	110	8	–	–	–
5:00 "	724	705	3	212	205	3	140	140	0	9.0	6.0	33
5:30 "	861	779	10	247	201	19	100	100	0	–	–	–
6:00 "	649	539	17	223	175	22	80	80	0	–	–	–
6:30 "	631	478	24	199	147	26	95	110	0	6.5	4.5	31
7:00 "	359	268	25	153	106	31	90	80	11	–	–	–

TABLE B-8. CONCENTRATION PROFILE ACROSS ROTOSTRAINER DURING STORM EVENT (500-micrometre screen aperture)

Sampling Time	SS			VSS			BOD_5			Settleable Solids		
	Raw Influent (mg/L)	Screen Effluent (mg/L)	Red. %	Raw Influent (mg/L)	Screen Effluent (mg/L)	Red. %	Raw Influent (mg/L)	Screen Effluent (mg/L)	Red. %	Raw Influent (mL/L)	Screen Effluent (mL/L)	Red. %
August 25/75												
9:45 am	357	378	0	211	201	5	70	60	14	-	-	-
10:00 "	1250	1210	3	340	300	12	140	115	18	7.3	6.5	11
10:15 "	1230	1110	10	330	270	18	115	125	0	-	-	-
10:30 "	940	868	8	314	277	12	110	160	0	11.0	8.5	23
10:45 "	994	792	20	476	319	33	180	130	28	-	-	-
11:00 "	580	526	9	255	190	25	95	75	21	5.7	4.4	23
11:15 "	431	423	2	156	143	8	70	60	14	-	-	-
11:30 "	339	350	0	127	117	8	50	46	8	4.5	3.5	22
11:45 "	358	362	0	128	125	2	46	50	0	-	-	-
12:00 "	441	429	3	150	143	5	44	46	0	3.9	3.0	23
12:15 pm	449	471	0	143	135	6	70	65	7	-	-	-
12:30 "	580	585	0	191	172	10	75	55	27	2.1	1.4	33
12:45 "	480	465	3	160	142	11	58	45	22	-	-	-
1:00 "	396	343	13	145	112	23	36	36	0	4.1	2.6	37
1:15 "	355	336	5	120	103	14	36	35	3	-	-	-
1:30 "	325	330	0	100	94	6	36	34	6	3.5	3.0	14
1:45 "	280	290	0	95	90	5	38	36	5	-	-	-

TABLE B-9. AVERAGE PERCENTAGE POLLUTANT MASS DISTRIBUTION ACROSS CWC - WET WEATHER OPERATION

			Percentage Mass Distribution									
			SS			VSS			BOD_5			
Date	Screen Capacity m^3/min (mgd)	Split	Cent.	Conc.	Enrich.*	Cent.	Conc.	Enrich.	Cent.	Conc.	Enrich.	From Split**
First flush portion of storm events												
November 2 /74	4.61 (1.46)	75/25	55.0	45.0	20.0	45.9	54.1	29.1	57.7	42.3	17.3	25
May 30/75	4.20 (1.33)	69/31	44.5	55.5	24.5	34.6	65.4	34.4	52.0	48.0	17.0	31
June 5/75	4.20 (1.33)	66/34	46.0	54.0	20.0	38.9	61.1	37.1	54.4	45.6	11.6	34
July 9/75	4.01 (1.27)	62/38	45.9	54.1	16.1	36.3	63.7	25.7	45.2	54.8	16.8	38
Mean	-	-	47.9	52.2	20.2	38.9	61.1	29.1	52.3	47.7	15.7	32
Storm Events without a first flush												
August 27/74	5.71 (1.81)	82/18	74.7	25.3	7.3	68.6	31.4	13.4	82.0	18.0	0	18
September 25/74	3.91 (1.24)	75/25	60.6	39.4	14.4	55.7	44.3	19.3	71.0	29.0	4.0	25
October 17/74	2.90 (0.92)	70/30	55.9	44.1	14.1	50.3	49.7	19.7	68.7	31.3	1.3	30
November 21/74	4.61 (1.46)	74/26	59.0	41.0	15.0	53.2	46.8	20.8	74.0	26.0	0	26
Mean	-	-	62.5	37.5	12.7	57.0	43.0	18.3	73.9	26.0	1.3	25

* Enrichment is mass transfer due to concentration effect only.

**The percent mass transfer from the split is the same for all parameters and is identical to the percentage of the feed volume that passes into the concentrate.

TABLE B-10. AVERAGE PERCENTAGE POLLUTANT MASS DISTRIBUTION ACROSS CWC - DRY WEATHER OPERATION

			Percentage Mass Distribution									
			SS			VSS			BOD_5			
Date	Screen Capacity m^3/min (mgd)	Split	Cent.	Conc.	Enrich.	Cent.	Conc.	Enrich.	Cent.	Conc.	Enrich.	From Split*
1974												
June	3.56 (1.13)	75/25	68.7	31.3	6.3	58.1	41.9	16.9	65.0	35.0	10.0	25
July	3.17 (1.00)	75/25	61.1	38.9	13.9	56.0	44.0	19.0	57.4	42.6	17.6	25
August	4.42 (1.40)	84/16	70.2	29.8	13.8	64.4	35.6	19.6	77.8	22.2	6.2	16
September	3.98 (1.26)	80/20	67.5	32.5	12.5	62.0	38.0	18.0	69.3	30.7	10.2	20
October	3.28 (1.04)	73/27	59.7	40.3	13.3	55.8	44.2	17.2	65.3	34.7	7.7	27
November	3.69 (1.17)	77/23	65.9	34.1	11.1	61.2	38.8	15.8	70.6	29.4	6.4	23
Mean	3.69 (1.17)	-	65.5	34.5	11.8	59.6	40.4	17.8	67.6	32.4	9.8	22.7
1975												
May	5.27 (1.67)	80/20	59.2	40.8	20.8	52.2	47.8	27.8	67.9	32.1	12.1	20
June	4.70 (1.49)	74/26	53.9	46.1	20.1	48.3	51.7	25.7	58.0	42.0	16.0	26
June	7.67 (2.43)	76/24	61.9	38.1	14.1	58.4	41.6	17.6	69.3	30.7	6.7	24
July	8.21 (2.60)	69/31	52.5	47.5	16.3	49.8	50.2	19.2	56.7	43.3	12.3	31
July	4.70 (1.49)	72/28	60.0	40.0	12.0	54.2	45.8	17.8	53.1	46.9	18.9	28
Mean	6.12 (1.94)	-	57.5	42.5	16.7	52.6	47.4	21.2	61.0	39.0	13.2	25.8

*The percent mass transfer from the split is the same for all parameters.

TABLE B-11. CWC CENTRATE CHARACTERISTICS DURING STORM EVENTS - AVERAGE PER STORM EVENT

Date	SS (mg/L)	VSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	Total P (mg/L)	Settleable Solids (mL/L)
1974							
June 19*	265	88	75	-	13	3.5	0.4
July 23*	327	140	140	-	23	5.6	-
August 27	124	51	33	-	14	2.9	0.1
September 25	181	108	57	-	28	5.5	3.0
October 17	203	69	54	-	19	3.7	0.3
November 12*	283	75	110	363	22	5.4	1.3
November 13	156	51	114	198	17	3.7	0.1
November 20*	293	87	60	204	13	3.4	0.8
November 21	106	46	66	181	12	2.4	0.1
1975							
May 20*	454	127	77	389	18	3.9	3.9
June 5*	449	131	89	383	16	4.4	2.6
July 9*	450	167	102	480	28	6.0	4.8
Average*	360	116	93	364	19	4.6	2.3
Minimum	265	75	60	204	13	3.5	0.4
Maximum	454	167	140	480	28	6.0	4.8
Average	154	65	65	190	18	3.6	0.7
Minimum	106	46	33	181	12	2.4	0.1
Maximum	203	108	114	198	28	5.5	3.0

*Storm with first flush condition.

TABLE B-12. CWC CONCENTRATE CHARACTERISTICS DURING STORM EVENTS - AVERAGE PER STORM EVENT

Date	SS (mg/L)	VSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	TKN (mg/L)	Total P (mg/L)	Settleable Solids (mL/L)
1974							
June 19*	470	200	120	-	16	5.1	7.5
July 23*	713	343	277	-	31	6.3	-
August 27	188	111	44	-	15	3.3	7.7
September 25	305	197	60	-	29	5.6	16.0
October 17	356	169	54	-	21	3.7	8.0
November 12*	400	113	136	433	23	5.9	8.7
November 13	198	88	135	226	18	4.2	8.3
November 20*	465	180	87	270	15	4.5	6.5
November 21	177	90	73	231	14	2.9	5.3
1975							
May 20*	660	246	104	572	20	5.1	14.3
June 5*	672	269	108	640	20	4.2	11.7
July 9*	729	375	203	1043	32	7.8	19.5
Average*	587	247	148	592	22	5.6	11.4
Average	245	131	73	229	19	3.9	9.1

*Storm with first flush condition.

TABLE B-13. MONTHLY PERFORMANCE DATA FOR CWC DURING DRY WEATHER OPERATION

	Average Monthly Percent Reductions*												
	SS		VSS		BOD_5		TKN		Total P		Settleable Solids		Number of
Date	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Samples
1974													
June	13	0-30	24	0-36	10	0-25	10	0-24	9	0-27	96	87-100	34
July	17	0-53	26	0-55	23	0-63	11	0-19	9	0-19	97	80-100	43
August	17	0-31	23	0-65	11	0-30	10	0-22	10	0-23	86	79-100	35
September	16	0-54	21	0-40	12	0-50	10	0-31	7	0-48	87	14-100	60
October	17	0-32	23	0-40	12	0-35	10	0-44	8	0-23	96	44-100	58
November	19	0-50	28	0-58	11	0-23	7	0-13	8.7	0-13	97	69-100	26
Mean	16.5	-	24	-	13	-	9.7	-		-	93	-	-
1975													
May	30	0-62	32	7-71	14	0-38	-	-	-	-	96	74-100	70
June	22	4-37	29	13-43	15	0-69	-	-	-	-	99	86-100	44
June**	22	0-45	28	0-54	14	0-40	-	-	-	-	95	81-100	12
July	19	9-34	25	15-36	26	0-33	-	-	-	-	96	74-100	9
July**	19	11-27	24	20-30	16	13-42	-	-	-	-	94	80-100	13
Mean	22.6	-	27.6	-	17	-	-	-	-	-	96	-	-
Overall Mean	19.3	-	25.7	-	14.7	-	9.7	-	8.7	-	94.5	-	-

Screen Aperture: 105 micrometres

* Percent reductions are arithmetic means and are based on concentration change.
**Operation at maximum possible flow rate.

TABLE B-14. CWC CENTRATE CONCENTRATIONS DURING DRY WEATHER OPERATION

	Arithmetic Means and Ranges of Concentrations											
	SS (mg/L)		VSS (mg/L)		BOD_5 (mg/L)		TKN (mg/L)		Total P (mg/L)		Settleable Solids (mL/L)	
Date	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
1974												
June	109	65-240	62	35-100	78	50-200	20	10-29	4.5	2.7-6.2	0.2	0-0.7
July	114	50-280	68	30-170	78	5-400	17	11-32	4.2	2.9-7.6	0.3	0-4.0
August	127	60-285	79	40-170	63	40-100	19	14-30	4.6	2.8-6.0	1.1	0-9.5
September	130	65-260	76	45-125	71	30-150	23	16-42	4.9	3.4-8.0	0.9	0-8.5
October	113	65-225	68	40-120	76	40-190	20	14-43	5.0	2.5-7.5	0.3	0-4.7
November	130	90-240	70	40-150	88	60-140	19	15-32	5.1	3.3-6.5	0.2	0-1.6
Mean	120.5	-	70.5	-	75.7	-	19.7	-	4.7	-	0.5	-
WPCP Mean**	48	-	-	-	54	-	-	-	-	-	-	-
1975												
May	114	50-348	62	20-92	67	36-140	-	-	-	-	0.2	0-1.3
June	94	62-143	62	41-94	62	35- 90	-	-	-	-	0.1	0-1.1
June*	105	72-134	73	54-97	72	50-140	-	-	-	-	0.3	0-1.3
July	115	96-164	73	61-113	62	50- 80	-	-	-	-	0.3	0-2.2
July*	105	91-123	70	61-83	69	44-110	-	-	-	-	0.3	0-1.2
Mean	106.5	-	68	-	66.4	-	-	-	-	-	0.2	-
WPCP Mean	44	-	-	-	57	-	-	-	-	-	-	-

* Operation at maximum possible flow rate.
**The WPCP mean refers to mean values for primary clarifier effluent.

TABLE B-15. CWC CONCENTRATE CONCENTRATIONS DURING DRY WEATHER OPERATION

	Arithmetic Means and Ranges of Concentrations											
	SS (mg/L)		VSS (mg/L)		BOD_5 (mg/L)		TKN (mg/L)		Total P (mg/L)		Settleable Solids (mL/L)	
Date	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
1974												
June	186	105-360	132	75-270	96	65-160	22	15-40	5.1	2.5-7.0	12.5	5.5-23.0
July	219	85-1160	166	60-1120	111	40-750	19	13-33	4.6	2.9-6.8	15.7	3.5-34.0
August	217	70-485	148	40-310	84	15-220	21	14-40	5.2	2.8-10.0	13.8	8.0-19.0
September	371	145-720	175	45-320	89	25-150	24	11-42	5.3	3.6-9.2	16.8	7.0-45.0
October	188	110-220	135	85-300	89	40-160	22	16-33	5.3	3.1-7.7	9.9	6.5-16.0
November	218	125-520	132	15-385	105	70-170	20	15-33	5.4	3.3-8.6	9.8	5.0-17.0
Mean	233	-	148	-	96	-	21	-	5.0	-	13.0	-
1975												
May	210	93-397	146	79-260	89	50-180	-	-	-	-	13.7	7.5-45.0
June	164	112-282	124	82-206	80	40-110	-	-	-	-	10.7	6.5-18.0
June*	210	155-292	171	118-244	94	65-150	-	-	-	-	22.0	13.5-31.5
July	216	164-341	164	116-204	93	70-150	-	-	-	-	15.0	11.0-21.0
July*	193	148-233	147	110-175	94	55-110	-	-	-	-	14.6	11.5-19.5
Mean	199	-	150	-	90	-	-	-	-	-	15.0	-

*Operation at maximum possible flow rate.

TABLE B-16. CONCENTRATIONS OF SOLVENT EXTRACTABLES (GREASE, OIL) IN RAW SEWAGE

Date		Time	Concentration (mg/L)	Date		Time	Concentration (mg/L)	Date		Time	Concentration (mg/L)
1974											
Oct.	10	10:00 am	24	Dec.	10	2:00 pm	4	June	5	1:20 pm	20
"	10	11:00 "	22	"	10	4:00 "	12	"	5	6:00 "	40
"	10	12:00 "	34	"	11	10:00 am	10	"	16	2:45 "	25
"	10	1:00 pm	20	"	11	4:00 pm	15	"	16	5:00 "	17
"	16	11:45 am	30	"	12	11:30 am	15	"	17	2:00 "	30
"	16	1:00 pm	11	"	16	11:00 "	18	"	18	1:00 "	20
"	16	5:00 "	13	"	16	1:00 pm	15	"	18	4:00 "	14
"	17	9:00 am	12	"	18	12:00 am	13	"	19	1:00 "	25
"	17	11:00 "	14	"	19	10:00 "	21	"	23	1:00 "	20
"	30	1:00 pm	45					"	23	4:00 "	25
"	30	4:00 "	102	1975				"	24	12:00 am	18
"	30	5:00 "	204	May	8	1:00 pm	31	"	24	3:00 pm	400
"	31	12:00 am	57	"	13	2:00 "	24	"	26	1:00 "	40
Nov.	14	12:00 "	8	"	22	1:30 "	31	"	26	3:00 "	25
"	14	1:00 pm	5	"	26	1:00 "	30	"	30	12:00 am	25
"	15	4:00 "	9	"	26	4:00 "	12	"	30	5:00 pm	16
"	18	4:00 "	42	"	27	4:00 "	16	July	2	12:00 am	25
"	19	3:00 "	14	"	27	5:00 "	13	"	2	4:00 pm	17
"	20	2:00 "	7	"	28	1:00 "	23	"	3	2:00 "	25
"	21	10:00 am	19	"	28	2:00 "	18	"	4	12:00 am	40
"	21	1:00 pm	17	"	29	11:30 am	25	"	7	1:00 pm	40
"	25	3:00 "	26	"	30	11:40 "	45	"	7	4:00 "	50
Dec.	2	12:00 am	20	June	3	1:00 pm	70	"	8	1:00 "	40
"	2	1:00 pm	24	"	3	4:00 "	19	"	8	4:00 "	25
"	3	1:00 "	50	"	4	2:00 "	30	"	9	9:30 am	95
"	9	12:00 am	10	"	4	4:00 "	17	"	9	12:30 pm	30

TABLE B-17. RESULTS OF SETTLING TESTS ON RAW SEWAGE AND CWC CONCENTRATE

DATE 1974	RAW SEWAGE Initial Concentration (mg/L)	RAW SEWAGE Concentration after 1 h* (mg/L)	RAW SEWAGE Percent Settled	CWC CONCENTRATE Initial Concentration (mg/L)	CWC CONCENTRATE Concentration after 1 h* (mg/L)	CWC CONCENTRATE Percent Settled
September 4	100	90	18	230	90	61
September 18	120	70	42	194	100	48
October 10	170	110	35	290	150	48
October 16	100	75	25	125	70	44
October 30	200	120	40	300	145	52
November 13	150	110	27	190	110	42
November 20**	500	250	50	675	200	70

* Sample taken at depth of 30 cm (1 ft) after one hour of settling.
**Storm event

Settling tests were done in 180 cm (6 ft) tall, 152-mm (6-inch) diameter acrylic columns.

TABLE B-18. OVERALL PERFORMANCES OF SCREENING DEVICES IN WET AND DRY WEATHER OPERATION

Device	Aperture (micrometres)	Nom. Hydraulic Loading $m^3/m^2 \cdot min$ (gpm/ft^2) W	D	Percentage Pollutant Removal on Mass Basis: SS (mg/L) W	D	VSS (mg/L) W	D	BOD_5 (mg/L) W	D	Settleable Solids (mL/L) W	D	Storm Events
CWC*	105	2.4 (50)	2.9 (60)	20.6	14.7	29.0	19.5	15.6	11.3	79.0	94.5	7
CWC+	105	2.4 (50)	2.9 (60)	55.6	38.7	64.0	43.5	50.6	35.3	-	-	7
DSM	305	0.8 (16)	0.8 (16)	19.2	12.5	34.0	17.3	17.8	7.3	58.1	62.0	4
Hyd.	762	0.9 (19)	0.9 (19)	9.4	7.7	21.5	10.0	5.2	6.0	22.6	11.5	5
Roto.	500	1.2 (25)	1.2 (25)	4.5	5.0	11.9	5.5	10.2	4.5	23.3	27.5	1

W - wet weather operation (first flush)
D - dry weather operation
* - mass pollutant separation by enrichment only
+ - mass pollutant separation by enrichment plus hydraulic flow splitting

Settleable solids were determined according to Imhoff cone test.

The above data were taken from all monitored storm events with a first flush, and the complete 1974/75 dry weather operations.

APPENDIX C

CAPITAL AND OPERATING COSTS

APPENDIX C

CAPITAL AND OPERATING COSTS

C1 General Discussion

The methods used for estimating capital and operating costs are given in this Appendix. Included is an example of how capital and operating costs for a typical wet weather CWC installation were estimated. Operating costs as a function of operating hours per year, taking into consideration the effects of screen size and number of installed units, are presented for the CWC, DSM screen, and Rotostrainer.

The total cost of installed equipment is affected by many factors. Although some of the factors, such as the cost of major equipment, are known and are not site-specific, other factors will depend on local conditions. Included among site-specific factors are wastewater characteristics and degree of treatment required. The following estimates for capital and operating costs are based on operating experience at the Belleville site and quotations from equipment suppliers. Major equipment costs are for 1976.

C2 Capital Costs

The capital costs of the Centrifugal Wastewater Concentrator, DSM screen, and Rotostrainer for different capacities or number of installed units are listed in Table C-1. These costs were estimated assuming stormwater treatment only rather than multi-purpose use. The hydraulic capacity under first flush conditions has been used to size the equipment. Operating costs were also developed for first flush conditions but they are not sensitive to raw sewage quality variations. No cost estimate was performed for the Hydrasieve because the unit tested, which was not equipped with a screen cleaning system, was found to perform relatively poorly.

All screening devices were costed using the largest units available. Smaller CWC and Rotostrainer units also were costed to facilitate comparison with the DSM screen in the size available. Because actual hydraulic capacities of the different types of screening devices available are not identical, the cost comparison is also expressed in dollars per million gallons per day.

TABLE C-1. SCREENING EQUIPMENT CAPITAL COST ESTIMATES

CWC 105-micrometres				DSM 305-micrometres				Rotostrainer 500-micrometres			
Number of Installed Units	Capacity m^3/d (mgd)	Total Cost $	Cost per 1000 m^3/d (mgd) of capacity $	Number of Installed Units	Capacity m^3/d (mgd)	Total Cost $	Cost per 1000 m^3/d (mgd) of capacity $	Number of Installed Units	Capacity m^3/d (mgd)	Total Cost $	Cost per 1000 m^3/d (mgd) of capacity $
1	4 091 (0.9)	24 700	6 038 (27 444)					1	4546 (1.0)	21 965	4832 (21 965)
1	8 182 (1.8)	40 200	4 913 (22 333)	1	3 409 (0.75)	17 900	5 250 (23 867)	1	13 638 (3.0)	52 665	3861 (17 555)
3	24 548 (5.4)	116 000	4 725 (21 481)	7	23 867 (5.25)	114 700	4 806 (21 847)	2	27 276 (6.0)	99 520	3649 (16 586)
4	32 731 (7.2)	154 000	4 705 (21 388)	10	34 095 (7.5)	156 800	4 599 (20 906)	3	40 914 (9.0)	152 185	3720 (16 909)

CWC - 5% discount on purchases of 3 or more units

DSM - 5% discount on purchase of 8 or more units

Cost estimates include: Complete screening equipment with associated screen cleaning equipment, feed pumps, electrical controls, piping, and fittings.

Hydraulic capacity for costing based on first flush conditions and on gallons applied to each type of screen.

Table C-1 shows that cost per mgd for each unit decreases with increasing installed capacity. Costs for the Rotostrainer are the lowest and decrease the most rapidly with capacity. It is emphasized, however, that these estimates include only the cost of the screen with associated automated cleaning devices, raw sewage feed pumps, electrical controls, piping, and fittings.

Additional capital expenses for locations within the Province of Ontario would include the costs of the following:

1) a winterized building for protection of screening equipment and/or electrical and control equipment;
2) equipment installation, foundations, and site preparation;
3) land;
4) engineering;
5) effluent and solids handling facilities; and
6) provision of power and water.

Each screening device evaluated is suitable for outdoor installation where there is no possibility of freeze-up during cold weather operation. If cold weather operation is a requirement then a suitable winterized heated building must be provided. The sizes of buildings required for single screens of maximum available size plus pumps and auxiliary equipment are listed in Table C-2. Building construction must allow for humid conditions on the inside. Large entry doors or access through the roof may be required for maintenance of equipment.

TABLE C-2. MINIMUM DIMENSIONS FOR BUILDINGS TO HOUSE SCREENING EQUIPMENT

Screening Device Single Unit	Dimensions m (ft) (L x W x H)
1.5-m (60-inch) diameter CWC	6.1 x 3.7 x 3.7 (20 x 12 x 12)
3-m (10-foot) Rotostrainer	7.6 x 4.9 x 3.0 (25 x 16 x 10)
1.8-m (6-foot) DSM Screen	6.1 x 3.7 x 3.7 (20 x 12 x 12)

The above dimensions allow for pumping and control equipment.

C3 Operating Costs

Operating costs for the 0.75 and 1.5-m (30 and 60-inch) diameter CWC, 1.2-m (4-foot) wide DSM screen, and a 1.2 m and 3.0-m (4 and 10-foot) wide Rotostrainer, are shown in Figures C-1, C-2, and C-3, respectively. Costs were derived from those prevailing in Belleville at the time of the study; they are shown in Table C-3. The cost of capital amortization has not been included. In each of the figures a range of operating costs is presented which shows the cost reductions of greater installed capacity. For the CWC and Rotostrainer, cost estimates for single smaller units comparable in size to the largest available DSM screen are included.

TABLE C-3. COMPONENTS OF OPERATING COST ESTIMATION - CWC UNIT

Item*	Unit Cost	Consumption
Electrical Power	1.0 ¢/kWh	60 hp/60-inch unit
Propane Gas	\$28.6/100 kg (\$13.0/100 lb)	100 lb/60 operating hours
ZEP Degreaser	\$1.10/L (\$5.0/gallon)	120 mL/5 min cycle
Screen Replacement	\$30.0/panel	3 panels/100 operating hours
Labour Cost	\$5.0/man-hour	1 man-h/3 operating hours or per storm
Maintenance	3.0% of major equipment	

*Electrical power is required for pumping raw sewage to the screen as well as for operation of the screen. Only power, labour, and maintenance costs would be included in estimates for the DSM and Rotostrainer.

Operating costs were estimated for screen utilization between 100 and 8000 hours per year and are shown in cents per 1000 gallons treated. The figures clearly show that unit operating costs decrease with increased screen utilization. For each device, costs decrease slightly with an increase in the number of installed units. The relatively steep decline in operating costs as a function of screen utilization, particularly for the DSM screen and Rotostrainer, is a reflection of the assumption that maintenance costs would be constant regardless of the number of operating hours per year (Table C-3).

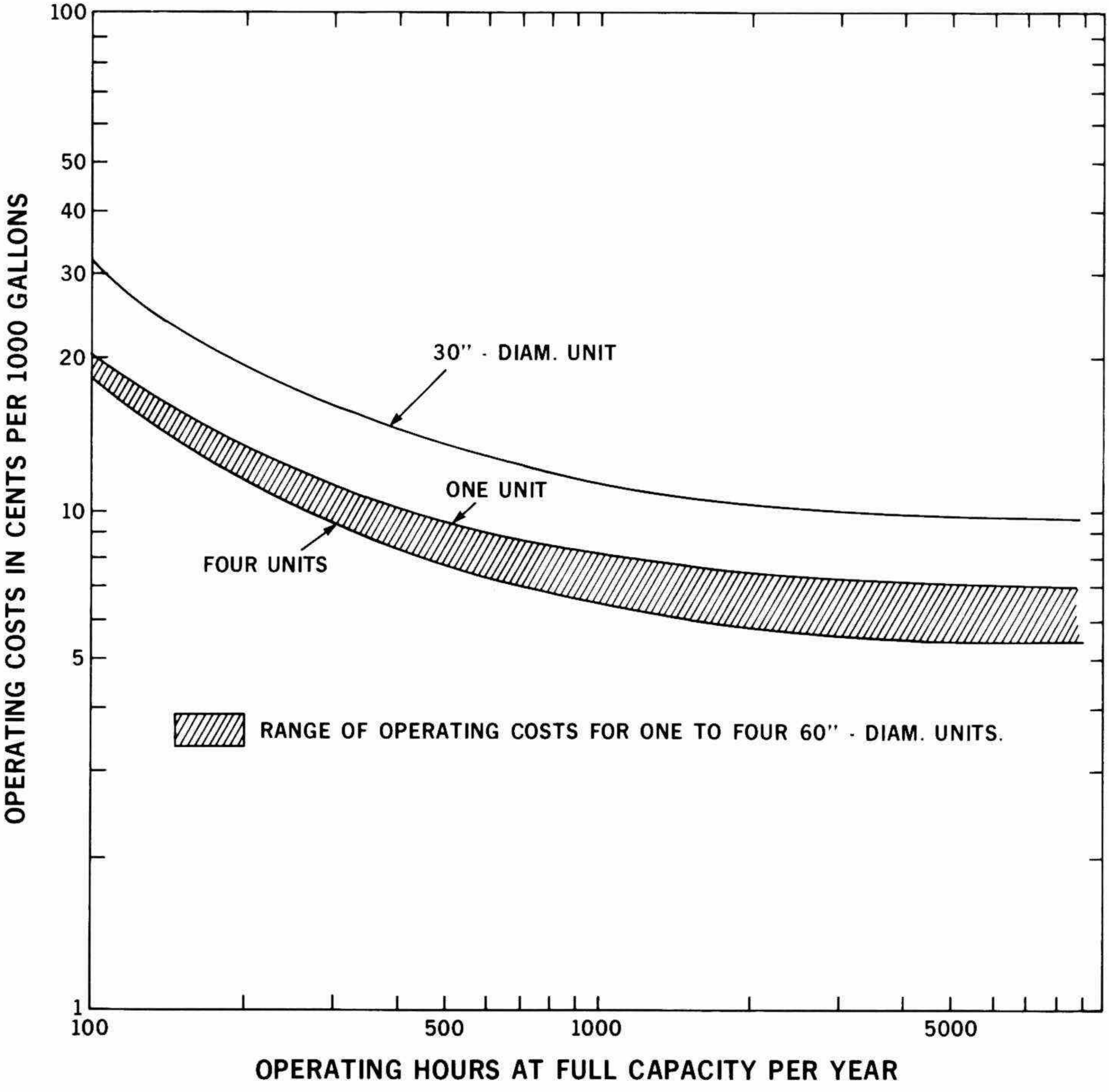


FIGURE C-1. CWC OPERATING COSTS

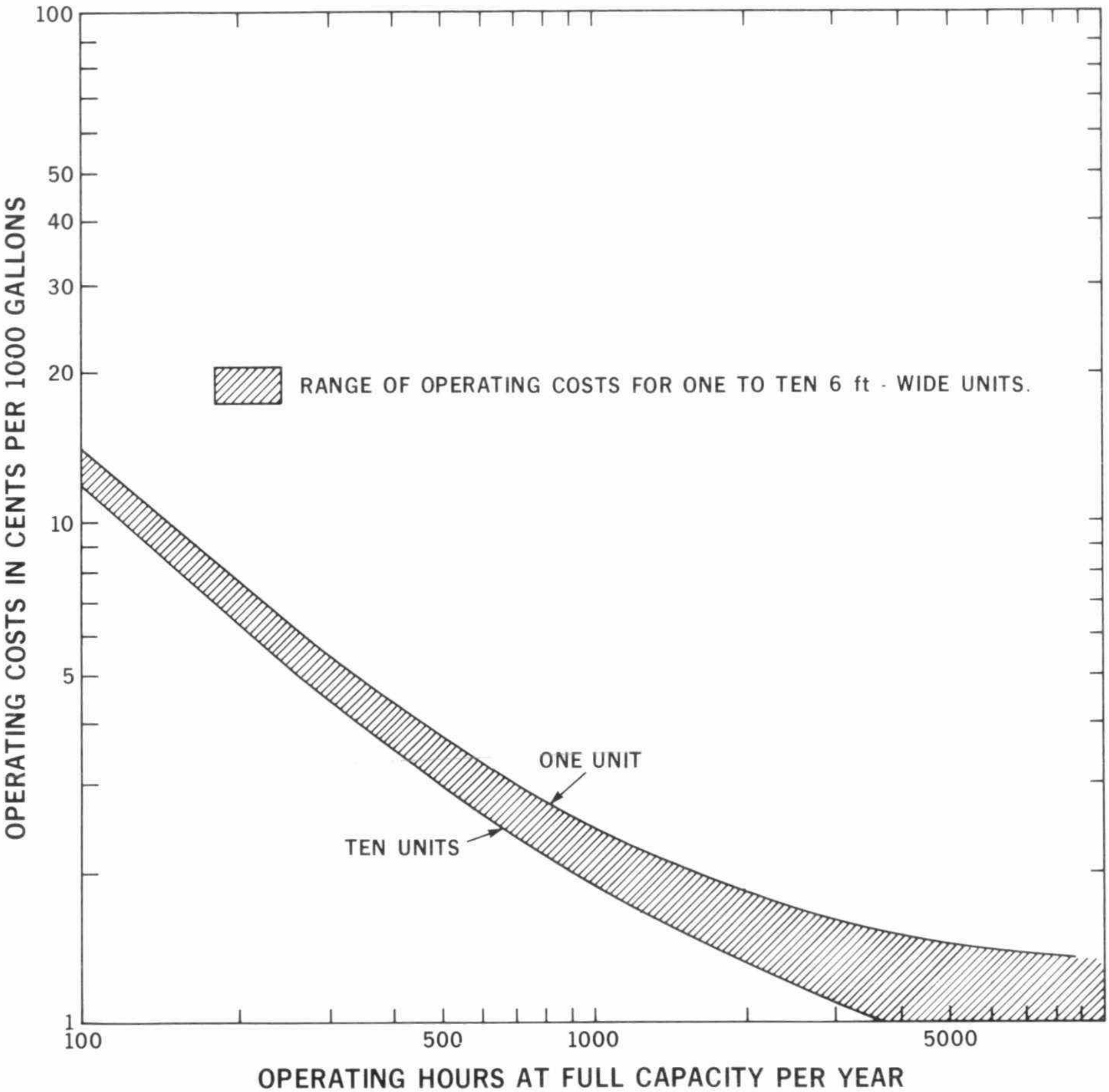


FIGURE C-2. DSM OPERATING COSTS

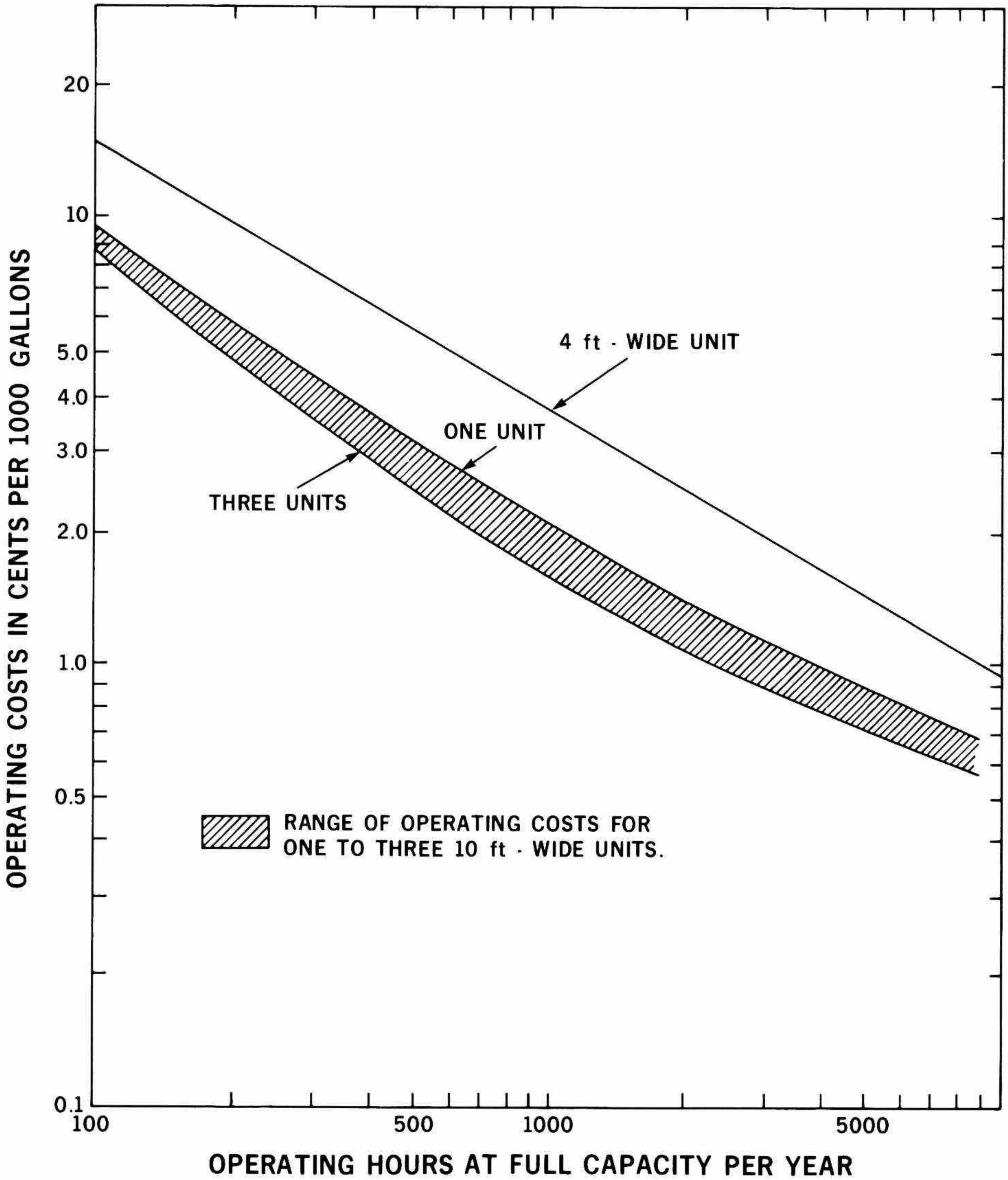


FIGURE C-3. ROTOSTRAINER OPERATING COSTS

C4 Estimation of Capital and Operating Costs for a New Installation

Capital and operating costs may be estimated using the following procedure, which requires historical data or modelling studies.

1) Decide on required screening capacity, based on peak flow during first flush conditions.
2) Select the type of equipment for the particular application. In the absence of new experimental data use the Belleville data for preliminary estimations.
3) From the above, size the equipment and determine the number of units needed.
4) From Table C-1 or vendors' information, estimate the capital cost for major equipment.
5) From historical data or modelling studies estimate the number of hours per year for which the equipment will be in operation at full capacity. If more than one unit is installed, determine what portion of the installed capacity will be in operation at any time.
6) Estimate operating costs in cents per cubic metre (cents per 1000 gallons or dollars per million gallons) treated, as illustrated in the following example, using Figures C-1, C-2, and C-3.

C5 Example for Estimating Capital and Operating Costs

Given data:

1) Screening capacity is required for a peak flow rate of 22 730 m^3/d (5.0 mgd).
2) Experimental studies indicate that a 1.5-m (60-inch) diameter CWC with a 165-mesh screen panels and 8200 m^3/d (1.8 mgd) capacity is desirable.
3) Background information showing the variation in raw sewage flow rate is available.

Number of CWC units required is 5.0/1.8 = 2.8; therefore, install three units. From Table C-1 the major equipment cost for three units is approximately $116 000. The background information relating to raw sewage flow rate is used to yield the following operating pattern:

1) 100 hours per year at full installed capacity (three units),

2) 500 hours per year at two-thirds installed capacity (two units),

3) 250 hours per yeat at one-third installed capacity (one unit).

The following table can now be constructed:

Operation h/year	Capacity m^3/d (mgd)		Volume Treated m^3 (mil gal)		Cost* ¢/m^3 ($/mil gal)		Annual Cost $/year
100	24 548	(5.4)	102 285	(22.50)	4.1	(186)	4 185
500	16 366	(3.6)	380 950	(75.00)	1.7	(79)	5 925
250	8 183	(1.8)	85 238	(18.75)	2.3	(106)	1 988
Total			528 473	(116.25)			12 098

$$\text{Average cost in ¢/m}^3 = \frac{12\ 098}{528\ 473} \times 100 = 2.3$$

$$\text{Average cost in \$/mil gal} = \frac{12\ 098}{116.25} = 104.0$$

or, 10.4 ¢/1000 gallons

*Taken from Figure C-1.